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DATA ANALYSIS METHODOLOGY FOR DAY/NIGHT INFLIGHT TACTICAL NAVIGATION

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U. S. Army
Research Institute for the Behavioral and Social Sciences

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Low-level helicopter navigation, both at night and during the day, is an essential portion of the Army's mission. Navigation performance, defined as the probability of navigating along a prescribed route or route segment without deviation, is a function of many factors including map type, terrain type, and time of day. Determining the effects of these factors is important for predicting performance of Army navigators, identifying factors critical to navigation, evaluating the probability of navigation success along a route,

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and developing training aids. The research reported here analyzed low-level flight experiment data to develop that information.

This report contains results of the analyses of helicopter low-level navigation data, (a) to determine the probability of navigation success along a route as a function of terrain type, (b) to develop a means of determining route difficulty, and (c) to develop a method of scoring student performance. The FORTRAN computer programs and the navigation data base used in the analysis are also documented.

Technical Report 411

DATA ANALYSIS METHODOLOGY FOR DAY/NIGHT INFLIGHT TACTICAL NAVIGATION

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Flight Training and
Aviator Selection

ARI Research Reports and Technical Reports are intended for sponsors of R&D tasks and for other research and military agencies. Any findings ready for implementation at the time of publication are presented in the last part of the Brief. Upon completion of a major phase of the task, formal recommendations for official action normally are conveyed to appropriate military agencies by briefing or Disposition Form.

FOREWORD

The Army Research Institute Field Unit at Fort Rucker, Alabama, is involved in a variety of research and development activities as it seeks to fulfill its mission of aircrew performance enhancement in the tactical environment. These activities include work in aircrew selection and training and are responsive to Army ROTE Project 2Q263743A772 and the Director of Training Developments, US Army Aviation Center. The work is conducted in-house and is augmented by contracts with organizations having unique capabilities in specific areas.

This report is of a contract effort which concerns the complex problem of establishing a suitable method of measuring day and night navigation performance when conducting flight at terrain flight altitudes. Its objectives were to develop a method of evaluation which would accurately describe navigation performance and which would be universally applicable in the institutional aviator training program and the ongoing field training program for the Army aviator.

JOSEPH ZEIDNER
Technical Director

DATA ANALYSIS METHODOLOGY FOR DAY/NIGHT INFLIGHT TACTICAL NAVIGATION

BRIEF

Requirement:

Knowledge of the effect of terrain, vegetation, hydrography and man-made features on the probability of helicopter navigation success is necessary to train student navigators to select flight routes and cues along a route. The objective of this study was to develop and validate methods of analyzing flight data, and to develop a slide rule for computing subject scores.

Procedure:

Flight data which consisted of maps marked with prespecified and actual flight routes were analyzed to identify the available navigation cues. For this analysis, the routes were divided into intervals so that the available cues (terrain, vegetation, hydrographic and man-made features) along the route could be assigned to intervals. Each interval was also categorized according to the number of navigation success and failures that occurred in that interval. From these data, the probability of navigation success in an interval as a function of the available cues was determined. Navigation success is defined as navigating along a prespecified route with deviations less than 100 meters. The data was also used to develop a slide rule suitable for scoring student navigation flights.

Findings:

Of the 45 terrain types of terrain features tested, one feature - the proportion of the route in one valley - was found to be the most significant single feature for predicting route probability of success.

Terrain cues for navigation should be selected depending on the "proportion of route in one valley" factor. Different terrain features aid or hinder navigation performance depending on that factor.

Navigation performance, as measured by the probability of navigation success (P_S), is a monotonic function of the number of terrain features of a given type - except where multiple draws preceed a draw where a route turn is required.

The route probability of success P_S can be calculated by the product of the constituent interval P_S's.

According to the evidence developed, the ambient light level does not affect navigation performance.

Evidence does not support the assertion that the existence of one or more clearings affects navigation performance; but, does support the assertion that clearings serve as dividers separating possible route paths.

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DATA ANALYSIS METHODOLOGY FOR DAY/NIGHT INFLIGHT TACTICAL NAVIGATION

INTRODUCTION

Low-level helicopter navigation, both at night and during the day, is an essential portion of the Army's mission. Navigation performance, defined as the probability of navigating along a prescribed route or route segment without deviation, is a function of many factors including map type, terrain type, and time of day. Determination of the effects of these factors is important information for predicting performance of Army navigators, identifying factors critical to navigation, evaluating the probability of navigation success along a route and developing training aids. The purpose of the research work reported here is to analyze low-level flight experiment data to develop that information.

This report is the final technical report on contract DAHC19-77-C-0042. It contains results from analyses of helicopter low-level navigation data to determine the probability of navigation success along a route as a function of terrain type, to develop a means of determining route difficulty, and to develop a method of scoring student performance. Documentation of the FORTRAN computer programs and the navigation data base used in the analysis are also included.

OBJECTIVES

The objectives of this research were as follows:

a. To develop an analysis methodology for inflight tactical terrain navigation data;
b. To develop appropriate, documented computer programs for analysis of existing and future data;
c. To compute validity/reliability coefficients of a composite performance score; and
d. To develop a cardboard "slide rule-type" device suitable for use by instructor pilots.

SUMMARY

Low-level navigation performance data were analyzed by classifying the terrain along routes according to type and calculating the probability of navigation success for each type. For this purpose, routes were divided into 500 meter intervals and the terrain features at or near each interval were recorded. Also recorded were the subject navigation performance data at each interval. Subject performance data consisted of the route intervals attempted and the route intervals successfully navigated. Computer files were developed containing the interval terrain data and the subject performance data. A computer program was written to permit search of these files and to determine the probability of navigation success (P_S) in intervals classified by terrain type and other factors. P_S's are computed for total routes and route intervals. P_S is the probability of navigation along the prespecified route or route interval without error.

Route and student scoring techniques were developed where, for the former, route P_S is calculated as the product of route interval P_S's. Interval P_S's have been determined as a function of terrain type. Thus, with this method, P_S can be predicted for new routes. A student scoring method (SSM) was developed which weights the score for each interval depending on the interval P_S.

Two methods of classifying terrain were found to be important for prediction of navigation success. One method uses local factors such as a road, hill, valley, stream, etc. to describe the terrain in or near a route interval. The other classification type describes the general terrain in a larger area - a route segment composed of multiple route intervals. The sequence lengths considered included full, half, and quarter routes. With this classification method, the "proportion of intervals" (PI) where a specified terrain condition exists was the variable used as an indication of general terrain type. A convenient notation for this variable is PI ( ) where the ( ) would indicate the terrain conditions of interest. For example, PI (1 valley) means the proportion of intervals in a single valley.

Three classes of general terrain type were formed based on the PI (1 valley) (e.g., a route segment is classified as Class A if 0 to 1/3 of the segment is in one valley, as Class B if 1/3 to 2/3 of the segment is in one valley, and Class C if greater than 2/3 of the segment is in one valley).

Salient terrain features resulting in either a significantly high (or low) P_S of route intervals were identified along with the associated P_S values. Furthermore, it was determined that differences in the general type of terrain result in differences in the salient terrain features in intervals, e.g., for each class of PI (1 valley) different terrain features, ponds, clearings, etc. are important.

A significant increase in P_S of intervals was found when four or more elevation features are present (e.g., four or more fingers, four or more hills, four or more draws). Another feature typically associated with increased P_S was two or more ponds. Other features were also important depending on the general terrain type.

Results also showed that ambient light level had no effect on P_S. Map type, however, had a significant effect with the Experimental Night Photomap (NP-1C) proving a significant increase in performance over map types AMD-3A and AMD-1B.

Another result showed that navigation errors along a route can be considered as independent errors since the distribution of numbers of errors per route (probability of exactly zero, one, two, etc. errors) follows binomial distribution. This result permits prediction of total route P_S by the product of the route interval P_S's.

Based on the development of P_S's as a function of terrain type, a student scoring method was developed. This scoring system normalizes the difficulty of the route, as measured by interval P_S's, so that the expected score for an average student is 1.00. The standard deviation for the student population tested (using the three types of maps referred to previously) is 0.05. The testing method provides a means for scoring students against a norm - even on new routes where experience data have not been collected.

GENERAL METHOD

Analyses were conducted using both night and day helicopter navigation data. Night data were used to develop analysis and performance measurement techniques. When the technique development was complete, it was evaluated using the day data.

The night navigation experiment employed 21 subjects each flying four different routes. Each subject was a recent graduate of the Initial Rotary Wing Program at Ft. Rucker, Alabama. Three types of maps were used where each subject used one type of map on all routes flown. Navigation performance data consisted of maps marked with the reference route and the actual flight path produced by the subject navigator. An instructor pilot served as pilot and marked the subject's navigational errors on the map.

Three types of experimental maps of the Petrey, Alabama, area were used in the night navigation experiment. One map, with white markings on a black background, was the Experimental Air Movement Data (AMD) Red-light Night-Use Prototype #3A. This map is referred to as AMD-3A. Another map with a white background was "AMD Experimental Prototype 1-B." This map is referred to as AMD-1B. Finally, a third map, "Experimental Night Photomap #1C" had a black background with colored contour lines and detail. This map is referred to as NP-1C.

The day navigation experiment design employed 10 routes with 10 subjects flying each route. Different subjects were used for each route requiring 100 total subjects. Data were collected in the same way as for the night data. Two types of maps were used - one type for five routes and the other type for the other five routes.

One map used for the day data was a topographic map of terrain near Ft. Rucker, Alabama, with contour intervals of 20 feet. This map is referred to as the "TM-20." The other map type is a photomap base with 50 foot intervals. This map is referred to as "PM-50."

For both night and day data, terrain features along each route were identified by map inspection. To facilitate the analysis, each route was divided into intervals 500 meters in length for night data and 1,000 meters in length for day data. The terrain features along and to the sides of each interval were recorded. Terrain features within 1,000 meters of the route were coded. This distance was assumed to be the limit of navigator visual purview. Terrain feature types were identified in the following categories:

Elevation Features

Ridge
Hill
Finger
Valley
Draw
Plateau

Vegetation Features

Dense Woods
Woods
Marsh
Clearing

Hydrographic Features

River
Stream
Intermittent Stream
Pond

Man-made Features

Highway
Road
Railroad
Buildings
Developed Areas
Bridges
Dams
Power Lines

In addition, parameters including location, size, altitude, shape, and orientation were recorded. A complete description of the terrain feature codes is presented in Appendix A.

Feature data were coded and entered into a computer file for subsequent analysis. The coding technique used parameter classification systems to categorize data and reduce the storage requirements. For example, the location of each feature near an interval was coded relative to the interval midpoint. The coding system is called a "Star Code" which uses a polar coordinate

system with eight angular sections and three range rings. Thus, a feature location such as the high point of a hill is identified by an angular sector (e.g., 0-45°) and range ring (e.g., 500 - 1,000 meters) with respect to the interval midpoint.

In addition to the route terrain file containing the terrain feature codes, a subject file containing subject experiment trial history was constructed. This file contains, for each subject and each route attempted, those intervals not attempted (missed), and the location of each navigation error. Intervals were missed for several reasons including navigation errors and premature termination of the particular trial. Typically one or more intervals were missed following an interval where a navigation error occurred - the navigator returned to the reference route but skipped a portion of the route. The portion of the route skipped consists of "missed" intervals. Subject errors were defined as deviations from the route exceeding 100 meters.

Analyses performed using the data files were classified as follows:

<u>Analysis of Night Navigation Data</u>

I Effect of Local Terrain Features on Interval P_S

Analysis A:	Frequency of Joint Occurrence of Local Terrain Features
Analysis B:	Local Terrain Features Considered Individually
Analysis C:	Combinations of Terrain Feature Type
Analysis D:	Existence of Clearings in an Interval
Analysis E:	Multiple Clearing Patterns Along a Route

II Effect of General Terrain Features on Route Segment P_S

Analysis F:	General Terrain Features
Analysis G:	Evaluation of the Length Restriction on "1 Valley"
Analysis H:	"1 Valley" Constituent Terrain Features
Analysis I:	PI (Clearings)

III Effect of Interaction Between Route Geometry and Terrain Characteristics on Route Segment P_S

Analysis J: Route Heading Change
Analysis K: Interaction of Heading Change and Route Terrain

IV Effect of Combinations of PI ( ) and Local Terrain Features on Route Segment P_S

Analysis L: PI (1 Valley) and Various Local Terrain Features

Development of a Route and Subject Scoring Method

Independence of Subject Errors
Calculation of Route P_S
Calculation of Subject Scores

Analysis of Day Navigation Data

Analysis M: Calculation of the Probability of Success (P_S) in intervals classified by a Single Terrain Feature Type
Analysis N: Prediction of a Route P_S as a Function of General Terrain Type Along the Route
Analysis O: Calculation of Interval P_S as a Function of Route Geometry

NIGHT NAVIGATION ANALYSIS

EFFECT OF LOCAL TERRAIN FEATURES ON INTERVAL P_S

Analysis A: Frequency of the Joint Occurrence of Features.

METHOD. Data files were searched to determine the number of intervals in which each type of feature occurs. From these results, an expanded set of variables was developed to further categorize each feature type so that the effect on performance of the number of features of a given type could be assessed.

The initial feature classification system used two categories: "no features of a specified type present," and "one or more

features of a specified type present." Examples of this initial classification system are "no ponds" and "one or more ponds." The analysis permitted, for some features, further expansion of the category "one or more features" into additional categories. A typical example was the expansion of the feature classification for fingers from "1 or more fingers" into "1, 2, 3 fingers," and "4 or more fingers." The expanded feature classification was selected so that each new category would occur in a large number of intervals - thus providing a more detailed description of the terrain feature than the original classification system. The expanded set of features along with the number of intervals over all routes in which the feature class exists are listed in Table 1.

Next, the number of intervals in which each combination of two types of features occur was determined. For example, the number of intervals in which both one or more ponds and one or more roads occur was determined.

RESULTS. Results of Analysis A, the expanded set of features, are shown in Table 1. In addition, Table 2 is a list of combinations of features that never occurred together at the same interval.

Analysis B: Local Terrain Features Considered Individually.

METHOD. Intervals were grouped according to the terrain feature classification referred to above. A computer program was written to enable search of the terrain feature and subject performance files. Computer output from the search is the total number of subject attempts and successes in the interval classes of interest. P_S for an interval class is then calculated as the number of successes divided by the number of attempts at all intervals within that class. Also, the P_S and number of attempts and successes were sorted automatically by the computer according to subject, route, and map.

A comparison of P_S's was made for each pair of terrain feature categories within a terrain type. For example, there are three categories in the finger terrain type: "no fingers," "1, 2, 3 fingers," and "4 or more fingers." A P_S was determined for each category and P_S's were compared for each pair as follows:

No fingers vs. 1, 2, 3 fingers
No fingers vs. 4 or more fingers
1, 2, 3 fingers vs. 4 or more fingers

Table 1

LISTING OF TERRAIN FEATURES USED IN ANALYSIS

Class ID Number	Type of Terrain Feature	Number of Features in Class	Number of* Intervals Terrain Class Exists
1	Ridge	None	75
2	Ridge	1 or more	57
3	Hill	None	10
4	Hill	1, 2, or 3	79
5	Hill	4 or more	43
6	Finger	None	13
7	Finger	1, 2, or 3	65
8	Finger	4 or more	54
9	Valley	None	12
10	Valley	1 Only	63
11	Valley	2 or more	57
12	Draw	None	17
13	Draw	1, 2, or 3	63
14	Draw	4 or more	52
15	Plateau	None	109
16	Plateau	1 or more	23
17	Rivers	None	37
18	Rivers	1 Only	73
19	Rivers	2 Only**	22
20	Stream	None	7
21	Stream	1 or 2	69
22	Stream	3 or more	56
23	I. Stream	None	21
24	I. Stream	1 or 2	77
25	I. Stream	3 or more	34
26	Pond	None	67

*Number of intervals along all night routes is 132.
**More than two did not occur in any interval.

Table 1 (Concluded)

LISTING OF TERRAIN FEATURES USED IN ANALYSIS

Class ID Number	Type of Terrain Feature	Number of Features in Class	Number of* Intervals Terrain Class Exists
27	Pond	1 Only	45
28	Pond	2 or more	20
29	Highway	None	81
30	Highway	1 or more	51
31	Road	None	6
32	Road	1 or 2	66
33	Road	3 or more	60
34	Railroad	None	117
35	Railroad	1 or more***	15
36	Building	None	67
37	Building	1 or more	65
38	Developed Area	None	108
39	Developed Area	1 or more***	24
40	Power line	None	108
41	Power line	1 or more***	24
42	Dam	None	88
43	Dam	1 or more	44
44	Bridge	None	82
45	Bridge	1 or more	50

*Number of intervals along all night routes is 132.
***More than one never occurred in an interval.

Table 2

PAIRS OF TERRAIN FEATURES THAT DID NOT CO-EXIST IN ANY INTERVAL

1. One or more ridges and one or more plateaus.

2. Four or more hills and one or more plateaus.

3. One or more railroads and one or more plateaus.

4. Four or more draws and one or more plateaus.

5. Four or more draws and two rivers.

6. One or more developed areas and three or more intermittent streams.

Differences in P_S that are statistically significant (observed $p \leq .10$) are noted. A feature category with a statistically significant improvement over another feature category is termed a "favorable" feature. The other feature category is termed an "unfavorable" feature.

Wilcoxon tests and t tests were used to test P_S's for significance on the pairs of terrain categories. Both tests were applied to a repeated measure experiment design since the subjects performed in both categories of each pair tested. Tests were conducted within a feature type such as "fingers." The pairings tested for fingers were those listed in the previous paragraph.

P_S data for certain feature classes might be considered a small sample for two reasons. One reason is that few subjects attempted intervals with that particular terrain classification. The other reason is that only a few intervals along the routes were associated with that terrain classification. Both the limited number of attempts and limited number of intervals were noted in these cases.

RESULTS. Results are summarized in Tables 3 and 4. Table 3 shows the significant terrain feature categories, the statistical significance (two tailed test), and the P_S for both feature types for data from all maps. In order to illustrate the differences found with one map type from the aggregated data of all map types, Table 4 shows results for map type NP-1C.

Analysis C: Combinations of Terrain Feature Types.

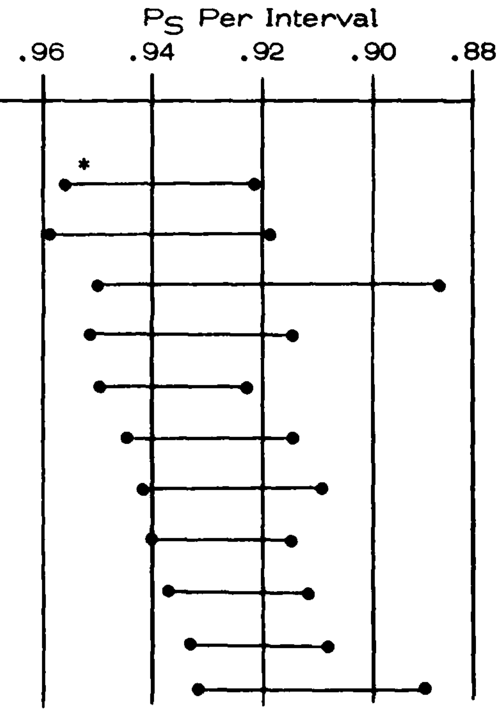
METHOD. The computer files were searched to determine P_S at intervals classified by combinations of terrain feature types. For example, P_S for all intervals containing both "1 or more ridges" and " 1 to 3 hills" were determined. P_S's for these intervals were compared to the composite P_S. The composite P_S is the P_S for all intervals regardless of terrain type. This comparison of deviation from the composite P_S was computed on a subject-by-subject basis yielding 21 subject samples. The P_S's were tested for significant differences from the composite P_S using the t test.

RESULTS. Results of Analysis C, the calculation of P_S for combinations of route features, are presented in Table 5. The significant feature classifications had an observed t statistic $>$ $t_{.10}(20)$ for a one tailed test.

Table 3

SIGNIFICANT FEATURE CATEGORIES - ALL MAPS

	Favorable Feature		Unfavorable Feature	p**
1.	2 or more ponds	vs	No ponds	(.01)
2.	2 or more ponds	vs	1 pond	(.001)
3.	4 or more fingers	vs	No fingers	(.05)
4.	4 or more fingers	vs	1, 2, 3 fingers	(.01)
5.	1 or more railroads	vs	No railroad	(.01)
6.	1 or more bridges	vs	No bridges	(.01)
7.	No valleys	vs	2 or more valleys	(.10)
8.	No stream	vs	1 or more streams	(.02)
9.	4 or more draws	vs	No draws	(.10)
10.	1 valley	vs	2 or more valleys	(.10)
11.	No plateau	vs	1 or more plateaus	(.02)



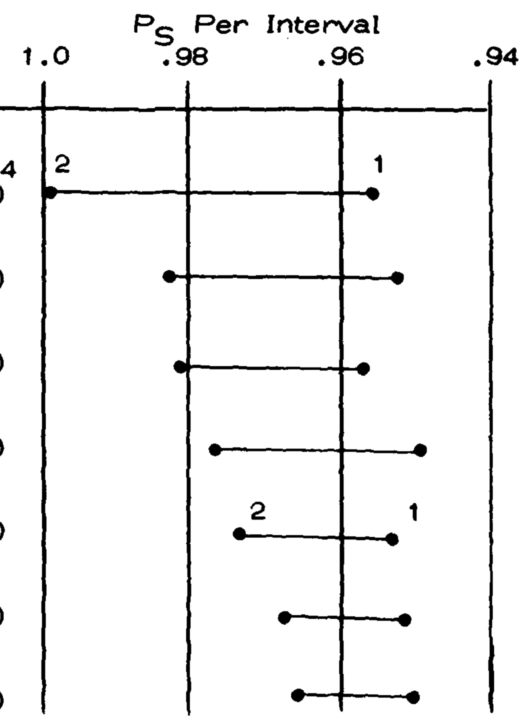
* Value of P_S for the favorable (unfavorable) feature is at the left (right) end of the line.

**Significance reported is for a t-test with df = 20.

Table 4

SIGNIFICANT FEATURE CATEGORIES - NP-1C MAP

Favorable Feature		Unfavorable Feature	p^3
1. No hills	vs	4 or more hills	(.05)[4]
2. 2 or more ponds	vs	No ponds	(.05)
3. 2 or more ponds	vs	1 pond	(.10)
4. 1 or more dams	vs	No dams	(.05)
5. No draws	vs	1, 2, 3 draws	(.10)
6. Bridges	vs	No bridges	(.05)
7. No buildings	vs	1 or more buildings	(.10)



[1] Values of P_S for the favorable (unfavorable) feature is at the left (right) end of the line.
[2] Only five intervals were classified in the favorable category.
[3] Significance reported is for a t-test with df = 5.
[4] Wilcoxon test, N = 6.

Table 5

P_S PER INTERVAL CLASSIFIED BY COMBINATIONS OF TERRAIN FEATURE TYPE

Feature Class	p One Tailed t-Test df = 20	P_S
No ridge, 1 or more highways, 3 or more roads	.01	.971
No ridge, 4 hills	.01	.969
1 or more highways, 3 or more roads, no railroad	.01	.969
No ridge, 4 or more fingers	.02	.958
4 or more hills, 4 or more fingers, 4 or more draws	.05	.958
4 or more hills, 1 to 3 fingers, 1 to 3 draws	.02	.958
4 or more fingers, 4 or more draws	.02	.957
1 to 3 hills, 4 or more fingers	.05	.956
No ridge, 3 or more roads	.02	.956
1 or more ridges, 4 or more hills, 1 to 3 draws	.10	.955
No ridge, 4 or more draws	.05	.954
1 or more ridges, 4 or more fingers	.10	.952
4 or more hills, 4 or more fingers	.10	.952
1 or more ridges, 3 or 4 hills	.10	.950
4 or more hills, 1 to 3 draws	.05	.950

The highest probability of success was a .971 the category "no ridge, 1 or more highways, 3 or more roads." Other categories yielding superior P_S of .969 were "1 or more highways, 3 or more roads, no railroad," and "no ridge, 4 hills."

Analysis D: Existence of Clearings in an Interval.

METHOD. The relationship between the existence of one or more clearings in an interval and P_S of that interval was studied by comparing the P_S of intervals with clearings to the P_S of intervals without clearings. Since each subject navigated along intervals both with and without clearings, a difference in P_S was calculated for each subject. A t-test for a repeated measure statistical analysis was used to evaluate the significance of the P_S differences.

RESULTS. Since the observed t was less than t .10 (20), results of the analysis showed no significant relationship between the existence of one or more clearings in an interval (within 500 meters of the interval) and P_S of that interval.

Analysis E: Multiple Clearing Patterns Along a Route

METHOD. The clearing patterns along a route may influence the P_S. Therefore an index termed the "confusion index" was defined based on the number of changes of vegetation to clearings or clearings to vegetation. Two measures used were the number of changes 300 and 600 meters from the route and were identified as T_3 and T_6 respectively. The index was taken as the ratio T_3/T_6. This index measures the number of short indentations of clearings along the route which might result in a navigator's confusion in distinguishing separated clearings from connected clearings.

Data were collected along the route 2,000 meters prior to each abrupt route turn. A navigation error for that turn was defined as any flight error exceeding 100 meter deviation from the route within the 2,000 meter interval. With P_S as the independent variable, regressions were run using the ratio T_3/T_6 and that ratio weighted by the number T_3, i.e., $T_3 \times T_3/T_6$ in univariate regressions, and both T_3/T_6 and T_3^2/T_6 in a multivariate regression.

RESULTS. Results are shown in Table 6. The univariate regressions using T_3/T_6 and T_3^2/T_6 as independent variables are not significant. But the multivariate regression is significant $F(1,10) = 4.83$, $p < .05$.

Table 6

RESULTS OF REGRESSIONS USING THE CONFUSION INDEX

Independent Variable(s)	Regression Coefficient	F Statistic	df	p
T_3/T_6		.25	1,10	NS
T_3^2/T_6		1.08	1,10	NS
T_3/T_6 and T_3^2/T_6	.464 -.0337	4.83	2,9	.05

EFFECT OF GENERAL TERRAIN FEATURES ON ROUTE SEGMENT P_S

Analysis F: General Terrain Features.

METHOD. Regression analyses were conducted using as independent variables "the proportion of intervals" (PI) along a route associated with specified terrain features. The dependent variable was the probability (P_S) of completing the route without navigational error. As an example, the variable PI (1 valley) which is the proportion of intervals along a route that are associated with "1 valley," was used to predict probability of success for that route.

Since there are only four routes, only four data sets are available for each regression analysis. With these limited data, only one or two independent variables could be used in the regression. However, additional tests were run to predict probability of success of one-half and one-quarter routes. This not only tests the power of the regression to predict performance on shorter route segments, but also makes additional data sets available. Thus, for one-half and one-quarter route regressions, eight and 16 data sets are available respectively. As a result, multiple independent variables were used in those regressions.

The first step in the analysis was to examine each of the 45 (expanded set of) terrain features to identify those with significant prediction of route P_S. Second, combinations of features were tested for multi-variable prediction of route and route segment P_S. F tests were used to test the statistical significance of the variance explained by each regression.

The effect of ambient light level, as measured by a photometer, was also tested. This test was to determine if there is a relationship between ambient light level and navigation performance. A regression analysis was conducted using the route P_S as the dependent variable and light level as the independent variable. Data for the test were from the 19 subjects who performed on route one.

RESULTS. Results of the univariate linear regression analysis are given in Table 7 which provides a list of single terrain features that can reliably predict route P_S. Also listed is p - the probability that the results could have been achieved by chance. "One valley only" was a significant predictor of route P_S with a positive correlation. Features "1 to 3 fingers," "2 or more valleys" and "1 to 3 draws" also provided significant prediction of P_S but with negative correlations, i.e., a decrease in feature frequency is associated with an increase in route P_S.

Table 8 gives the results of multiple linear regression tests. Two combinations of variables provided significant prediction of P_S: "1 to 3 fingers, 2 or more ponds" and "1 valley, 1 or more plateaus."

Table 7

TERRAIN FEATURES PROVIDING SIGNIFICANT PREDICTION OF ROUTE P_S IN A UNIVARIATE LINEAR REGRESSION

Feature Class	R	F Statistic	p, df = (1,2)
1 to 3 Fingers	-.920	11.1	.073
1 Valley Only	+.967	30.1	.031
2 or More Valleys	-.944	16.5	.055
1 to 3 Draws	-.952	19.6	.047

Table 8

MULTIVARIATE LINEAR REGRESSION FOR PREDICTION OF ROUTE P_S

Feature Class	R	F Statistic	p, df = (1,2)
1 to 3 Fingers, 2 or more Ponds	.999	881.2	.023
1 Valley, 1 or more Plateaus	.997	119.3	.064

Tables 9 and 10 give regression results for predicting P_S over half-route segments. Table 9 presents the results for univariate regressions and reveals that valley, draw, and finger feature classifications provide significant predictions. Valley classification "1 valley" and "2 or more valleys" can account for over 70 percent of the one-half route P_S variance.

Table 9

UNIVARIATE LINEAR REGRESSION FOR ONE-HALF ROUTE SEGMENTS: ELEVATION FEATURES

Feature Class	R	F Statistic	p, df = (1,6)
1 Valley	+.871	18.9	.005
2 or More Valleys	-.856	16.6	.01
4 or More Draws	+.777	9.1	.05
1, 2, 3 Draws	-.728	6.7	.05
4 or More Fingers	+.675	5.0	.10

Table 10

MULTIVARIATE LINEAR REGRESSION FOR ONE-HALF ROUTE SEGMENTS: ELEVATION FEATURES

Feature Class	R	F Statistic	p, df = (2,5)
1, 2, 3 fingers, 1 valley	.960	30.1	.002
No plateau, 1 valley	.957	23.9	.005
1 plateau, 1 valley	.951	23.8	.005
2 or more valleys, 1, 2, or 3 fingers	.932	16.9	.01
2 or more valleys, 1 or more plateaus	.906	11.6	.025
2 or more valleys, no plateau	.906	11.6	.025
1 valley, 4 or more draws	.884	9.0	.025
4 or more hills, 4 or more draws	.882	8.8	.025
4 or more hills, 2 or more valleys	.874	8.1	.05
1, 2, 3 hills, 1 valley	.872	8.0	.05
1, 2, 3 hills, 2 or more valleys	.866	7.5	.05
1, 2, 3 hills, 4 or more draws	.863	7.3	.05
4 or more hills, 1 valley	.872	8.0	.05
1, 2, 3 fingers, no plateau	.854	6.8	.05
1, 2, 3 fingers, 1 or more plateaus	.854	6.8	.05
4 or more fingers, 1 valley	.871	7.9	.05
4 or more fingers, 2 or more valleys	.859	7.0	.05
No valleys, 4 or more draws	.843	6.2	.05
1 valley, 1, 2, 3 draws	.871	7.9	.05
2 or more valleys, 1, 2, 3 draws	.858	7.0	.05
2 or more valleys, 4 or more draws	.857	6.9	.05
4 or more hills, 1, 2, 3 draws	.837	5.9	.05

Table 10 gives the results of the multivariate regression for one-half route segments. Again, valley classifications in combination with "1, 2, 3 fingers," "no plateau," "1 plateau" provide significant prediction and account for over 80 percent of the one-half route P_S variance.

Results of regression for one-quarter route P_S prediction are listed in Tables 11 and 12 for univariate and multivariate analyses respectively. For one-quarter route P_S prediction, fingers, draws, hills, and plateaus appear to be more significant than valleys; however, the proportion of variance explained is approximately 20 percent for the univariate analysis and less than 40 percent for the multivariate analysis.

Results of the prediction of route P_S as a linear function of light level showed that light level is not a significant prediction of route P_S.

Analysis G: Evaluation of the Length Restriction on "1 Valley".

METHOD. Prediction of probability of success (P_S) for full routes and route segments demonstrates that performance is, in part, a function of general terrain type, and that general terrain type can be characterized by PI (1 valley). However, as shown in Tables 7, 9, and 11, the variance explained by a univariate regression (employing PI (1 valley) as the independent variable) decreases as the length of a route segment decreases. This may be due, in part, to the definition of 1 valley which specifies that the length of 1 valley exceed 2,500 meters. But, the length of a one-quarter route segment is also approximately 2,500 meters. Thus, the lower length limit in the definition of 1 valley may prohibit accurate prediction of P_S for quarter-route segments. In order to determine if this lower bound on length causes the reduction in variance explained, a new definition for a single valley was formed and used in a regression analysis to predict route and interval P_S. This type of single valley, which does not involve a length limit, is termed "salient valley," and is defined as follows:

> An interval is classified as containing a salient valley when all of the following conditions are met:
>
> 1. The specified route is in a valley over the length of the interval.

Table 11

UNIVARIATE LINEAR REGRESSION FOR ONE-QUARTER ROUTE SEGMENTS: ELEVATION FEATURES

Feature Class	R	F Statistic	p, df = (1,14)
4 or more draws	.512	5.0	.05
No plateau	.446	3.5	.10
1 or more plateaus	.446	3.5	.10
2 or more valleys	.432	3.2	.10

Table 12

MULTIVARIATE LINEAR REGRESSION FOR ONE-QUARTER ROUTE SEGMENTS: ELEVATION FEATURES

Feature Class	R	F Statistic	p, df=(2,13)
1, 2, 3 fingers, 4 or more draws	.627	4.2	.05
1, 2, 3 fingers, 2 or more valleys	.600	3.7	.10
4 or more hills, 4 or more draws	.574	3.2	.10
1, 2, 3 hills, 4 or more draws	.562	3.0	.10
No plateaus, 4 or more draws	.560	3.0	.10
1 or more plateaus, 4 or more draws	.560	3.0	.10

2. All other terrain depressions (if any) within 1,000 meters of the route have a floor slope greater than 100 feet per 1,000 meters, or have a floor that rises to the horizon.

3. The width between the "high points" to either side of the valley is less than 2,000 meters.

4. The change of route path elevation is less than 60 feet over the length of an interval (500 meters).

Terrain along each route was classified at each interval according to the salient valley definition. A regression analysis was conducted using the "proportion of intervals containing a salient valley" (PI (salient valley)) as the independent variable and P_S as the dependent variable. Regressions for segment lengths of 1 route, 1/2 route, and 1/4 route were calculated and the variance explained by the PI (salient valley) regressions was compared to that of PI (1 valley) regressions.

RESULTS. Comparison of the regression analysis using "1 valley" and "salient valley," in terms of variance explained, is shown in Table 13. It is clear that the P_S prediction capability of the "salient valley" classification decreases as the lengths of the route segment decreases, and that the salient valley prediction explains less variance for full and half routes than does the "1 valley" classification.

Table 13

COMPARISON OF "1 VALLEY" TO "SALIENT VALLEY" BASED ON VARIANCE EXPLAINED IN THE UNIVARIATE REGRESSION ANALYSIS

	"1 Valley"		"Salient Valley"	
	R	R^2	R	R^2
Full Route	.968	.938	.760	.578
Half Route	.872	.760	.561	.314
Quarter Route	.401	.161	.468	.217

Analysis H: "1 Valley" Constituent Terrain Features.

Comparative analysis of the performance prediction capability of the PI (1 valley) and PI (salient valley) variables led to the understanding that that type of terrain is identified by several constituent terrain and route conditions. Since one or more of these conditions may be as important to navigation performance as the aggregate "1 valley" classification, performance relationships of each condition and combinations of conditions were investigated. The four conditions listed in the previous section as the definition components for a salient valley were used and are repeated in Table 14 for reference. Note that a symbol is defined in the table to represent each condition, e.g., V_T true means "it is true that the route follows a single valley;" obviously, V_F false means that the route is not in the valley. In addition to the four conditions previously described, a fifth condition, route heading change was investigated and is listed in the table.

METHOD. First, correlation analyses were conducted with the five factors referenced above for full route, half route, and quarter route navigation performance (P_S). The variables measuring each condition for the correlation analysis were the proportion of intervals (PI) along the route segment at which each condition is true. A Pearson product-moment correlation (r) coefficient was determined for each correlation. A test of the null-hypothesis that $r = 0$ was applied to the correlation results.

Next, the performance prediction of each of the five conditions and combinations of conditions was investigated using a univariate regression analysis. In this analysis, the independent variable representing each condition or combination of conditions was the proportion of intervals in which a specified logical function of the conditions is true. For example, one logical combination of the conditions is:

$$X_1 = V_T \cdot D_T \cdot N_T \cdot E_T \cdot H_T$$

where "·" is the logical AND operation.
Thus, the variable X_1 is true only when all of the constituent factors are true. The corresponding independent variable used in the regression analysis is the portion of intervals at which X_1 is true, i.e., PI (X_1). Consider another example:

$$X_2 = V_T \cdot D_T \cdot N_T \cdot E_T \cdot H_F$$

According to this equation, X_2 is true only when all the factors specified are true; note, however, that (differing from the previous

Table 14

VARIABLE DEFINITIONS

V_T	Route follows a valley over length of interval.
D_T	No depression (other than the depression the route follows) rises less than 100 feet (or to the elevation of high features) over 1,000 meters to either side of the interval.
N_T	The depression which the route follows is less than 2,000 meters in width to the bounding linear elevation to either side of the interval.
E_T	Route rises less than 60 feet over the length of interval.
H_T	Heading changes less than 10^{o} over length of interval.

equation) H_F* is true only when heading change is not less than 10^{o} over the length of the interval. A further example which illustrates yet another type of logic function is:

$$X_3 = V_T \cdot D_T \cdot N_T \cdot E_T$$

In this example, the heading condition is not specified so that the logic "does not care" if the heading condition is true or false.

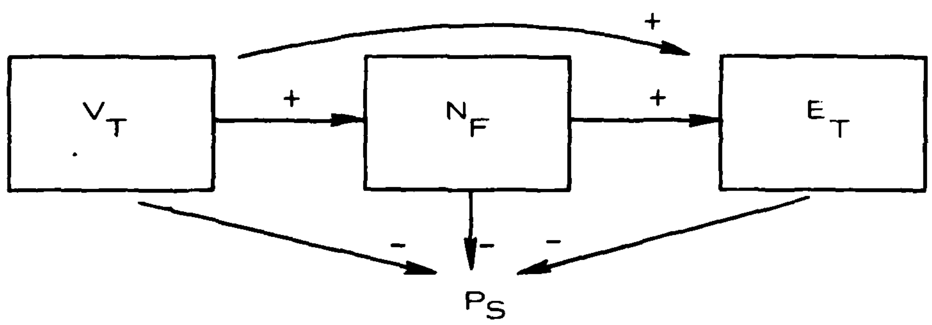
The performance prediction analysis used all combinations of the five conditions taken five at a time, four at a time, three at a time, two at a time and each individual condition. Three sets of regression analyses were conducted using the dependent variable (P_S): full route, half route, and quarter route respectively.

*H_F is the logical inverse of H_T so that when H_T is true H_F is false and visa versa.

RESULTS. Results of the correlation analysis are given in Table 15. As shown in the table, the significance of the correlation varies with route segment length. Recall that the amount of data available increases for decreasing length of the route segment, i.e., 4, 8, 16 samples for full, half, and quarter route segments respectively. Figure 1 presents a different organization of the data, where V_T, N_F, E_T are shown to be positively correlated. N_F is the logical inverse of N_T, i.e., N_F true means that the valley width (distance between the high points) exceeds 2,000 meters. Each of these three factors is negatively correlated with performance.

Figure 1

CORRELATED CONDITIONS



Results of Table 15 show that the V_T factor (specifying that the route is in a single valley) taken as a single factor, is highly correlated with performance (P_S) for half and full routes. But, the N_F factor (specifying that the width of the valley is greater than 2,000 meters) has a larger correlation with P_S for quarter routes and the correlation is almost as large for half and full routes. Since the E_T factor (specifying a gradual slope of the valley floor) is highly correlated with N and V, but does not have as large a correlation with performance as does N and V, the E factor was eliminated in the regression studies. By the same reasoning, either N or F could have been eliminated since they are correlated; however, since one is not superior for predicting P_S for all route segment lengths, both were used in the regression analysis.

Table 15

RESULTS OF CORRELATION ANALYSIS

Condition Combinations	Quarter df = 14	Half df = 6	Full df = 2
	Pearson Product-Moment Correlation Coefficient r — Route Length		
V_TD_T	-.251	-.119	-.547
V_TN_T	-.575**	-.709**	-.908*
V_TE_T	.807***	.674*	.843
V_TH_T	.494*	.132	-.239
V_TP_S	-.111	-.753**	-.982**
D_TN_T	.414	.484	.217
D_TE_T	-.538**	-.599	-.434
D_TH_T	.070	-.346	.757
D_TP_S	.013	.352	.661
N_TE_T	-.572**	-.773**	-.913*
N_TH_T	-4.29	-.548	-.190
N_TP_S	.504**	.771**	.812
E_TH_T	.304	.576	.155
E_TP_S	-.033	-.881	-.759
H_TP_S	.225	.074	.419

*$p \leq .10$ H_0: $r = 0$

**$p \leq .05$

***$p \leq .01$ H_1: $r \neq 0$

Tables 16, 17, and 18 provide results of the univariate regression analyses using as the independent variables the logical combinations of the five terrain and route factors described above.

Analysis I: PI (Clearings).

METHOD. A correlation analysis was performed to determine the Pearson product-moment correlation coefficient (r) for the "proportion of route intervals with one or more clearings" and route segment P_S. Route segment lengths for full route, half route and quarter route were used.

In an additional analysis, a multivariate regression was used to determine the effect of combinations of clearings and a specified terrain characteristic on route segment performance. For the analysis, one independent variable was the "proportion of route intervals with one or more clearings" while the other independent variable was the proportion of route intervals in "1 valley."

RESULTS. Table 19 provides the results of the correlation analysis and reveals that the correlation between the "proportion of route intervals with clearings" and route segment P_S is small. Table 19 also provides the results of the multivariate regression analysis. Results of univariate regressions previously reported which use terrain characteristics as the independent variable are also presented so that the variance explained with and without clearings can be compared.

EFFECT OF INTERACTION BETWEEN ROUTE GEOMETRY AND TERRAIN ON ROUTE SEGMENT P_S

Analysis J: Route Heading Change.

METHOD. The effect of route heading change on interval P_S was tested with a repeated measure sign test. For this test, a route heading change was deemed to occur if the route heading change over a 1,000 meter interval exceeded 10^o. P_S for each subject for intervals with a heading change was compared to that for intervals without a heading change. The sign test was used to evaluate the statistical significance of the result.

RESULTS. No significant relationship was found to exist between interval P_S and heading change.

Table 16

RESULTS OF CORRELATION ANALYSIS: QUARTER ROUTE

Condition Combinations	PI ( )	r	r^2	p* df = 14 n = 1
$N_T H_T$	.416	.645	.416	.001
$N_F H_F$	.077	−.456	.208	.01
$N_F H_T$	.113	−.444	.197	.01
$N_T H_F$				NS
$N_F D_F$	.181	−.570	.325	.01
$N_T D_F$	.208	.555	.308	.01
V and D, V and H combinations				NS
– –	– –	– –	– –	–
$N_F H_F D_F$	.054	−.501	.251	.01
$N_T H_F D_F$	.083	.435	.189	.1
$N_F H_T D_F$	.127	−.478	.228	.1
$N_T H_T D_F$	.125	.527	.278	.01
$N_T H_T D_T$	.292	.440	.193	.1
Other combinations of N,H,D				NS
Combinations of V,H,D				NS

PI ( ) is the proportion of intervals where the combination is true.

*Reference Sokal, R. R., Rohlf, F. J., Biometry, W. A. Freeman & Company, 1969, pp. 516-518.

Table 17

RESULTS OF CORRELATION ANALYSIS: HALF ROUTE

Condition Combinations	PI ( )	r	r^2	p* df = 6 n = 1
$N_T H_T$	.417	.744	.553	.01
$N_T H_F$	.219	..679	.461	.1
$N_F H_F$	.078	−.899	.808	.001
$N_F H_T$				NS
$N_F D_F$	.180	−.851	.724	.001
$N_T D_F$	.210	.775	.600	.01
Other combinations of N, D				NS
$V_F H_T$	.122	.736	.541	.01
Other combinations of V, H				NS
$V_F D_T$	.141	.718	.515	.01
Other combinations of V, D				NS
$N_T H_T D_T$	.290	.711	.505	.01
$N_T H_T D_F$	.127	.689	.474	.1
$N_T H_F D_F$	.084	.63	.397	.1
$N_F H_T D_F$	.127	−.701	.491	.1
$N_T H_F D_F$	.054	−.784	.615	.01
Other combinations of V, H				NS

PI ( ) is the proportion of intervals where the combination is true.

* Sokal, op. cit., pp. 516-518.

Table 18

RESULTS OF CORRELATION ANALYSIS:

Condition Combinations	PI ( )	r	r^2	p* df = 6 n = 1
$N_F H_F$	.078	-.974	.949	.01
Other combinations of N,H				NS
$N_F D_F$	.179	-.961	.924	.01
Other combinations of N,D				NS
$V_F H_F$	.097	.929	.863	.1
Other combinations of F,H				NS
- - -	- -	-	-	- -
$N_T H_T D_T$	.293	.903	.815	.1
$N_F H_F D_F$	.054	-.948	.898	.1
Other combinations of N,H,D				NS
$V_F H_F D_T$	.099	.999	.998	.001
Other combinations of F,H,D				NS

PI ( ) is the proportion of intervals where the combination is true.

*Sokal, op. cit., pp. 516-518.

Table 19

RESULTS OF CORRELATION AND REGRESSION ANALYSIS FOR CLEARINGS

Correlation between route segment P_S and proportion of route intervals with a clearing.

Route Segment	r
Full Route	.262
Half Route	.303
Quarter Route	.106

P_S variance (R^2) explained by the proportion of route intervals with a clearing and PI (1 valley).

Terrain Characteristics	Segment Length	Univariate Regression (terrain characteristic only)	Multivariate Regression (terrain and clearing)
1 Valley	Full Route	.937	.956

Analysis K: Interaction of Heading Change and Route Terrain.

METHOD. The effect of heading change and route terrain on route, half route, and quarter route P_S was evaluated with a multivariate regression analysis. Several regression analyses were conducted using PI (heading change) for one independent variable and PI (specified terrain characteristics) for the other independent variable. The specified terrain characteristics were those previously found to be related to P_S.

RESULTS. Results of the regressíon analysis are presented in Table 20. The results of univariate regression analyses using the specified terrain characteristics as the independent variable are also included in the table. This aids in identifying the additional variance (if any) explained by the introduction of heading change information into the regression.

Table 20

SIGNIFICANCE OF HEADING CHANGE COMBINED WITH TERRAIN FEATURE

Feature Class	Univariate Regression (terrain Characteristic only) R	R^2	Multivariate Regression with Heading Change R	R^2	Significance of Multivariate Regression p
Effect of Heading Change on Full Route Prediction					
1 valley	.967	.937	.972	.946	NS
1 - 3 draws	-.952	.907	.993	.986	NS
2 or more valleys	-.944	.891	.992	.983	NS
1-3 fingers	-.920	.847	.996	.993	.10
Effect on Heading Change on Half Route Prediction					
1 valley	.871	.759	.886	.784	.025
2 or more valleys	-.856	.734	.885	.783	.025
4 or more draws	.777	.605	.816	.666	.10
Effect of Heading Change on Quarter Route Prediction					
4 or more draws	.512	.263	.691	.477	.025
1 or more plateaus	-.446	.199	.602	.363	.10
2 or more valleys	-.432	.187	.537	.288	NS

Correlation between heading change and P_S is -.415 (full route)

EFFECT OF COMBINATIONS OF PI ( ) AND LOCAL TERRAIN FEATURES ON ROUTE SEGMENT P_S

Analysis L: PI (1 Valley) and Various Local Terrain Features.

METHOD. This analysis employed two ways of classifying intervals. First, groups of intervals were classified by the proportion of intervals in which "1 valley" occurred (PI (1 valley)). The value of PI (1 valley) was classified into three categories as follows:

Category	Proportion of Intervals Associated With One Valley
A	PI (1 valley) = .00 - .33
B	PI (1 valley) = .34 - .66
C	PI (1 valley) = .67 - 1.00

One-quarter route segments were classified as shown above. This provides three categories according to general type of terrain over several route segments, i.e., successive intervals. Rationale for this additional classification is that navigation performance may be a function of general terrain type over several successive intervals and the specific terrain type in intervals.

Intervals classified in Categories A, B or C according to the value of PI (1 valley) were further classified by terrain type and the associated P_S was determined by computer search. Again, t-tests tests were applied to determine the significance of P_S for each type of terrain. For these statistical tests, the P_S for the doubly classified intervals (i.e., classified by general terrain type (PI (1 valley) and specific terrain in intervals) were compared to the composite P_S for all intervals. Within each PI (1 valley) category, i.e., for each class of general terrain, terrain features that result in an exceptionally high or low interval P_S are noted. An exceptionally high (favorable) or low (unfavorable) P_S is one that is significantly different statistically from the P_S for all intervals.

RESULTS. Calculation of P_S for intervals classified by general terrain type along a route segment and also classified by terrain type in an interval, resulted in the data presented in Tables 21, 22, 23, and 24. Results presented are the intervals with a significantly different P_S from that computed over all intervals, i.e., the composite P_S. Results are organized by each PI (1 valley) class.

DISCUSSION OF THE ANALYSIS OF NIGHT NAVIGATION DATA

EFFECT OF ELEVATION FEATURES ON INTERVAL P_S (ANALYSIS A, B, AND C)

Results show that elevation features which include "4 or more fingers," "no valleys," "1 valley," "4 or more draws," "no plateau" are significantly related to navigation performance. Comparison between "4 or more fingers" versus "no fingers" shows that a substantial increase in the interval P_S is obtained with 4 or more fingers (.936), and a substantial decrease is obtained for intervals where no fingers are present (.894). These results show that superior performance for all maps is obtained where multiple fingers and draws exist. This suggests that terrain ruggedness increases the potential for the existence of unique terrain features which can be useful terrain cues for the navigation.

The increase in interval P_S with "1 valley" over both "no valleys" and "2 or more valleys" suggests that while ruggedness of terrain and a single valley path are of value to navigation, the existence of more than one valley may lead to navigation errors because of the alternative routes present. Performance differences associated with valley classifications are not just interval oriented, but suggest a way of classifying the general terrain along a route segment consisting of multiple intervals in sequence. This concept of characterizing the general terrain was considered in Analyses F, G, H, and I.

The improved performance where there is "no plateau" can be interpreted by observing that the existence of a single plateau means that an elevated and generally low lying area of limited features is present immediately adjacent to the route. This lack of salient features may lead to the low probability of success where routes pass near plateaus.

Table 21

P_S FOR DOUBLY CLASSIFIED ROUTE INTERVALS
ALL MAPS

Features With Significantly Different P_S	p t-test df = 20	Favorable Feature	Unfavorable Feature
4 or more fingers	.01	.980*	
No bridge	.02		.899
1 or more buildings	.05		.894
No draw	.01		.886
No fingers	.05		.878

P_S for all other features is .976 (18.7% of Class A intervals)

PI (1 valley) - Class A

No stream	.001	1.000	
1 or more railroads	.001	1.000	
2 or more ponds	.001	.983	
4 or more hills	.001	.979	
1 or more bridges	.001	.969	
1 or more dams	.01	.962	

P_S for all other features is .883 (14.6% of Class B intervals)

PI (1 valley) - Class B

2 or more ponds	.001	.988	
1 or more dams	.001	.983	

P_S for all other features is .931 (83% of Class C intervals)

PI (1 valley) - Class C

*Only five intervals

Note: P_S over all intervals without regard to terrain features is .936.

Table 22

P_S FOR DOUBLY CLASSIFIED ROUTE INTERVALS
MAP NP-1C

Features With Significantly Different P_S	p t-test df = 5	Favorable Feature	Unfavorable Feature
None			
P_S for all features is .973			
PI (1 valley) - Class A			
4 or more hills	.02	1.00	
No stream	.02	1.00	
2 or more ponds	.02	1.00	
1 or more railroads	.02	1.00	
P_S for all other features is .949 (31.7% of Class B intervals)			
PI (1 valley) - Class B			
1 pond	.02	1.00	
1 or more dams	.02	1.00	
No ponds	.10		.946
One or more of the above features are present at all Class C intervals			
PI (1 valley) - Class C			

Note: P_S for subjects using Map NP-1C over all intervals without regard to terrain features is .968.

Table 23

P_S FOR DOUBLY CLASSIFIED ROUTE INTERVALS
MAP AMD-3A

Features With Significantly Different P_S	p t-test df = 6	Favorable Feature	Unfavorable Feature
No bridges	.05		.853
1 or more dams	.10		.847
	PI (1 valley) - Class A		
1 or more railroads	.001	1.000	
No stream	.001	1.000	
2 or more ponds	.02	.984	
1 or more highways	.01	.983	
1 or more bridges	.05	.971	
1 or more dams	.01	.966	
1 pond	.01	.966	
1 or more ridges	.10	.965	
1 to 3 fingers	.02	.963	
4 or more hills	.10	.962	
	PI (1 valley) - Class B		
1 or more dams	.05	.979	
No stream	.10		.872
	PI (1 valley) - Class C		

Note: P_S for subjects using Map AMD-3A over all intervals without regard to terrain features is .919.

Table 24

P_S FOR DOUBLY CLASSIFIED ROUTE INTERVALS
MAP AMD-1B

Features With Significantly Different P_S	p t-test df = 7	Favorable Feature	Unfavorable Feature
No bridges	.10		.887
1 or more buildings	.10		.873
1 to 3 fingers	.10		.866
1 or more highways	.05		.863
	PI (1 valley) - Class A		
1 or more railroads	.001	1.000	
No streams	.001	1.000	
4 or more hills	.020	.977	
1 or more hills	.001	.970	
2 or more ponds	.05	.970	
1 or more dams	.05	.942	
	PI (1 valley) - Class B		
2 or more ponds	.001	1.000	
3 or more streams	.01	.981	
1 or more dams	.05	.975	
4 or more fingers	.02	.965	
4 or more draws	.1	.963	
No ridge	.1	.957	
1 to 3 hills	.1	.956	
No buildings	.1	.952	
	PI (1 valley) - Class C		

Note: P_S for subjects using Map AMD-1B over all intervals without regard to terrain features is .928.

EFFECT OF MAP TYPE ON INTERVAL P_S (ANALYSIS A, B, C)

Comparing the results of all maps with the results of the NP-1C map for the terrain category "no hills" illustrates the superior performance obtained with the NP-1C map even though the category "no hills" occurred at just 10 intervals over all four routes. These areas consisted of a low wide valley where the specified routes were along a relatively straight path and dead reckoning could be used for navigation. This type of terrain lacks salient navigation features, yet inspite of this, resulted in very superior performance for the subjects using the NP-1C map. The fact that performance over all maps did not show this elevation category as superior indicates that with the other two types of maps (AMD-3A, AMD-1B) performance must have been poor. It must be concluded that some differences in the NP-1C map permits successful navigation in terrain classified as "no hills." Similar results occurred with the elevation category "no draws" where subjects using the NP-1C map provided superior performance. For all maps, man-made features "one or more railroads," "one or more bridges" provide significant improvement of performance, presumably because these features are unique cues.

It is found that bridges are consistently important cues with the NP-1C map even though bridges are not coded on this type of map. Apparently, the existence of a bridge can be reliably assumed (i.e., from a road crossing a stream) by the navigator; the bridge symbol is not required.

EFFECT OF HYDROGRAPHIC FEATURES ON INTERVAL P_S (ANALYSIS A, B, AND C)

Results shown in Table 3 reveal that the category "2 or more ponds" is a very significant factor in navigation performance over "no pond" and "1 pond." Intervals associated with two or more ponds provide a .986 probability of success per interval. Apparently, two or more ponds provide a higher likelihood of the unique pattern than does one pond or other terrain features.

Table 4, which gives the results for subjects using the NP-1C map, shows a similar result of the pond for "2 or more ponds" revealing that ponds are an important navigation clue regardless of the type of map used.

The result which indicates that "no stream" is superior to "1 or more streams" is curious since one would expect streams

would provide good terrain-following cues. However, analysis of this result shows that frequently associated with the "no stream" category are rivers, valleys, and draws which are excellent terrain-following cues.

EFFECT OF VEGETATION FEATURES ON P_S (ANALYSIS D, E, AND I)

According to the results of Analyses D and I, the P_S's for intervals with clearings (and also those without clearings) were not found to be significantly different from the composite P_S. Based on this result, there is no support for believing there is a relationship between the "existence of one or more clearings in an interval" and navigation performance in that interval.

In contrast, both experienced and student pilots state that clearings are an important and often used cue for navigation. Since in the analysis the measure of a clearing was simply its existence without regard to size, shape, or number of clearings and without regard to the uniqueness of the clearing shape with respect to other clearings in the area, failure to detect a significance relationship with performance may be due to the simplified method of coding clearings.

The shape of clearings was considered in Analysis I - particularly with regard to the fidelity of the shape of clearings depicted on a map. (It is recognized, of course, that the shape of actual clearings is not constant and can change with season of the year, construction, and farming practices.) But, the actual clearings were not at hand so it was reasoned that comparison of clearing shape between one type of map and another, especially photo maps, would provide at least one logical test of how clearings might be used by navigators. The argument is: if there is a consistency of clearing shape across map type, then it would at least be possible for a navigator to use clearing shape for navigation. Conversely, if clearing shapes were inconsistent over map types, then it would not be possible for a navigator to rely on clearing shapes on all maps. This comparative analysis was a qualitative rather than quantitative one. Results were as follows: First it was observed that for the three maps used to obtain the night navigation data, the general shape of a large clearing is consistent from one map to another; but, the shape of smaller clearings and small indentations of larger clearings are not consistent across map types. Second, map contour lines tend to define a clearing shape to the eye even when the clearing does not follow the contour - this factor may lead to navigator error when extracting clearing shape from a map. Finally, it was observed that the specified

routes often pass over vegetation between clearings or at the edge of clearings. This seems to occur where a course heading change is made. Typically the route specifies that the aircraft pass one or more clearings prior to making a heading turn, and when the turn is made, the flight path is at a clearing edge or over vegetation between clearings.

This tendency suggests a hypothesis regarding clearing usage. It might be (particularly in the absence of a clearing with a uniquely reliable shape) that clearings are used as dividers separating possible paths which extend from an existing route direction to an alternate route direction. With this hypothesis as to clearing usage, a route might be laid out to pass by one or more clearings and then turn to pass between or along the edge of a clearing. The route designer's rationale is that the navigator would be able to count clearings along the route prior to the turn and that counting or recognition of clearings would aid in recognizing the correct location of the turn. Analysis E, "Multiple Clearing Patterns Along a Route," was designed to test that hypothesis.

The results of Analysis E do not support the assertion that T_3/T_6* and T_3^2/T_6*, taken as individual factors, are related to P_S; but, with the multivariate regression significant ($p \leq .05$) prediction of P_S was obtained. The factor T_3/T_6 was positively correlated with performance while T_3^2/T_6 was negatively correlated with performance. This result means that P_S is high where deep indentations of vegetative terrain separate clearings - this occurs where an indentation, if large enough to exist 300 meters from the route, extends to 600 meters from the route. Conversly, P_S is low where indentations exist at 300 meters but not at 600 meters from the route. Thus it seems that deep separations between clearings presumably aid the navigator in distinguishing adjacent clearings and result in improved performance. This tends to support the hypothesis that navigators at least use the number of clearings along a route to successfully identify a route turn. The result is consistent with the comparison of clearing shapes represented in different types of maps: large (at least 600 meter) indentations of vegetative terrain and clearings are reliable indicators of clearing shape. Conversely, the hypothesis states that small indentations are not reliable indicators of clearing shape.

*T_3/T_6 is a measure of the extent of an indentation (by vegetation) of a clearing and T_3^2/T_6 is a measure of the number of such indentations.

The second factor (T_3^2/T_6) used in the multivariate regression reflects the number of vegetation indentations both small and large. Its negative correlation with P_S suggests that many clearings along a route prior to a turn result in low navigation performance.

EFFECT OF GENERAL TERRAIN FEATURES ON ROUTE SEGMENT P_S (ANALYSIS F)

A search of all the 45 terrain features used as general terrain classifiers resulted in only four feature classes with significant prediction of total route performance. This prediction uses the proportion of intervals (PI) along the route associated with the feature type as the independent variable in a regression analysis. The dependent variable was route segment P_S. The proportion of a route containing the terrain feature of interest is a variable describing the general terrain along a route or route segment. This terrain classification is applicable to many successive intervals - not just one interval.

"One valley" was the best single feature predictor accounting for 93.7 percent of the variance. Furthermore, "1 valley" was positively correlated with the route P_S implying that the higher the proportion of "1 valley" along the route, the higher the expected navigation success.

The other three feature categories "1 to 3 fingers," "2 or more valleys," and "1 to 3 draws" which provided significant route P_S prediction were negatively correlated with P_S. This implies that the less frequent the type of terrain along a route is present, the higher the route P_S. Previous results (Analysis B) confirm that the existence of multiple valleys at an interval produces reduced P_S - perhaps because of the multiple opportunities for error.

The same previous analysis shows that "4 or more fingers" and "4 or more draws" provide improved P_S at intervals. Thus, it is not inconsistent to observe the negative correlation of "1 to 3 fingers" and "1 to 3 draws" with route P_S.

When all combinations (taken two at a time) of the four terrain features found to be significant in the univariate analysis were tested, only two combinations were found to be significant - "1 to 3 fingers, 2 or more ponds" and "1 valley, 1 or more plateaus." Both combinations accounted for a high percentage of

route P_S variance. However, it must be noted that route (P_S) scores were used and thus only four data points were available.

The test of the relationship between the variable PI (1 valley) and P_S for one-half and one-quarter route segments shows that a strong relationship exists for one-half route segments. P_S over one-quarter route segments have a weak relationship to PI (1 valley). This suggests that there may exist a lower bound to the length of route segments that can be classified according to general terrain type. Analysis G was an investigation of the existence of such a bound and is discussed in the following paragraph.

No significant relationship was found between ambient light level and performance.

SIGNIFICANCE OF THE LENGTH RESTRICTION OF "1 VALLEY" (ANALYSIS G)

Results of Analysis G show that the 2,500 meter lower limit on the definition of "1 valley" does not restrict the performance prediction capability of the "1 valley" variable. Thus, the factor PI (1 valley) can be used to predict performance of routes and route segments greater than 2,500 meters in length.

SIGNIFICANCE OF "1 VALLEY" CONSTITUENT TERRAIN FEATURES ON P_S (ANALYSIS H)

The term "1 valley" has been defined in a very specific way and it is well to review that definition here. Further, the effect of an route P_S of each component of that definition was investigated. That study revealed critical aspects of the definition. A terrain interval is classified as a "1 valley" interval if it satisfies all of the following conditions:

1. Route follows a valley over length of the interval. (V_T)

2. No depression (other than the depression the route follows) rises less than 100 feet (or to the elevation of high features) over 1,000 meters to either side of the interval. (D_T)

3. The depression which the route follows is less than 2,000 meters in width measured across the bounding elevation on each side of the interval. (N_T)

4. Route rises less than 60 feet per 1,000 meters over the length of interval. (E_T)

5. Route interval is greater than 2,500 meters in length.

Note that the definition of "1 valley" is similar to that of a salient valley except that "1 valley" has the additional 2,500 meter minimum length restriction.

Results of the correlation analysis as shown in Table 15 reveal that the factors V_T, N_F, E_T are highly correlated and therefore cannot be considered as independent factors. This relationship is a result of the route design which specified routes where the three factors coincide frequently. Because of this relationship, the associated terrain could be referred to as "route in valley," "a wide valley" or "a flat valley." Also it is not possible to logically associate navigation performance (P_S) with just one of these terrain characteristics. Note also that these conditions are negatively correlated with P_S.

Tables 16, 17, and 18 show that all statistically significant condition combinations involving $N_T(N_F)$ are always positively (negatively) correlated with route segment P_S. This correlation property is true for all route segment lengths (i.e., quarter, half, full routes) and is true when N_T (and N_F) is combined with the other variables (H and D)). (The same correlation property holds true for the V factor which was previously shown to be correlated with the N factor.) This consistent correlation property strongly suggests that the relationship between P_S and the overall N condition (and therefore V and E) dominates that of the D and H factors.

Considering now specific condition combinations and referring to Table 16, combinations N_TH_T, N_FD_F, N_TD_F explain 41 percent, 32 percent and 30 percent, respectively, of the variance of the interval P_S. The first combination (N_TH_T) correlation coefficient (.645) is an increase over the individual correlation coefficients of N_T (.504) and H_T (.225). This evidence tends to support the assertion that the combination N_TH_T is a better predictor of quarter route P_S than N_T or H_T alone.

The assertion is reinforced by the results of the half route analysis shown in Table 17. In addition, the combination N_FH_F accounts for 80 percent of the variance and N_FD_F accounts for 72 percent of the variance. This suggests that a high proportion of navigation errors occur at intervals classified as either N_FH_F or N_FD_F, i.e., where the valley width exceeds 2,000 meters and either route heading changes exist or there are other depressions. Check of the possible assertion that the triple combination $N_FH_FD_F$ may provide an even better P_S prediction (i.e., explain more variance) reveals a lower variance explained (61 percent) as shown in Table 17.

Finally, the results of full route regressions also show that N_FH_F and N_FD_F combinations explain 95 percent and 92 percent, respectively, of the full route P_S variance. Apparently, it can be concluded since these combinations are negatively correlated with route P_S, that the combination of conditions represented by N_FH_F and N_FD_F should be avoided in route design. Also, it is seen that the triple combinations $N_TH_TD_T$ and $N_TH_FD_F$ explain less variance than do the double combinations referred to above. This suggests that the specific combinations of conditions N_FH_F and N_FD_F define terrain conditions to be avoided and that terrain represented by the dual combinations provides a more serious problem than does terrain represented by the individual conditions N_F, H_F, and D_F.

$N_F H_F$ and $N_F D_F$ specify conditions to be avoided in route design; but, according to the results shown in Table 18 the combination $V_F H_F D_T$, which is positively correlated with route P_S, explains 99.8 percent of the route P_S variance. This result suggests that where route heading changes occur (i.e., H_F is true), the route should not be in a valley and there should be only one local terrain depression.

EFFECT OF ROUTE HEADING CHANGE ON ROUTE SEGMENT P_S (ANALYSIS H, J, K)

The relationship between route heading changes and route segment P_S was investigated in three ways. Analysis J, which was a test of the effect of a route heading change considered above without regard to local terrain conditions, revealed that there is no significant effect of heading change when it is considered as an isolated variable. Results of Analysis H clearly reveal that heading changes that occur together with wide valleys (recall that wide valley occurred frequently with "routes in the valley" and a "valley floor with a gradual slope") lead to frequent navigation errors. Analysis H also revealed that route heading changes occurring where there is only one valley (i.e., no other depressions), but where the route is not in the valley, are frequently associated with navigation success. Finally, the results of Analysis K which are summarized in Table 20 again show that combining heading change together with certain terrain features does permit explanation of additional route segment variance over that of the terrain feature alone.

Based on these analyses it must be concluded that there is an interaction of route heading and terrain features that should be considered in route design. In contrast, however, it is seen that the terrain conditions of "1 valley" permit a prediction of route segment P_S that explains considerable variance, but that the combination of "1 valley" and heading does not explain much additional variance. Therefore, the condition "1 valley" can be used to predict route segment P_S without regard to route heading changes.

EFFECT OF TERRAIN CLASSIFIED BY GENERAL TERRAIN TYPE AND BY LOCAL TERRAIN FEATURES (ANALYSIS L)

Rationale for selecting three PI (1 valley) factor classes was to establish three easily visualized PI (1 valley) factor conditions. PI (1 valley) Class A represents general terrain type not frequently

associated with one valley. PI (1 valley) Class B represents a mixed general terrain type where the route enters and leaves a single valley. PI (1 valley) Class C represents route segments almost totally in a single valley. It is believed that this classification system permits an individual to easily translate from the more abstract "PI (1 valley) factor" classes to map areas associated with the general terrain type.

However, the numerical values for interval P_S for the three classes suggest that perhaps two classes would be more appropriate. P_S for Class A are different (lower) than those of Classes B and C. Perhaps the reason for this empirical merging of Classes B and C is that in Analysis E, one-quarter route segments were used and classified according to the PI (1 valley) factor. Within each of these categories, significant local terrain features were determined. But the regression analysis (Analysis D) showed that prediction of one-quarter route P_S was not as significant as prediction of P_S for one-half and full routes. Perhaps if one-half routes had been used for Analysis E, three performance groupings would have emerged. There does not seem to be an advantage of three groups over two, but from the results of the regression analysis (Analysis D), three groups were expected. In the subsequent analysis (route and student scoring) three PI (1 valley) factor classifications are used to preserve notation.

Since analysis has shown the importance to interval P_S of general terrain classified as "proportion of intervals associated with "1 valley," methods of identifying "1 valley" terrain on a map should be reviewed. "One valley" is taken to mean terrain where the valley floor is of a constant elevation (less than 60 feet elevation change per 1,000 meters) and both elevated sides of the valley are visible (within 1,000 meters) from the flight path along the valley floor. Terrain that otherwise would be classified as a valley, but where the elevation is increasing or decreasing, are classified as "draws." Also, terrain that is broad and flat so that the distance from one side elevation across the floor to the other side elevation is greater than 2,000 meters, is not classified as "1 valley." Further, a valley was defined as having a length exceeding 2,500 meters. Thus, only terrain consisting of a narrow, single valley at least 2,500 meters long where the valley floor is of constant elevation is classified as "1 valley."

It is interesting to note that exceptional terrain features associated with PI (1 valley) factor Class A are mostly unfavorable features. Thus, referring to Table 21 which applies to all maps, if there are no bridges, no draws, or no fingers at an interval, performance is expected to be degraded as evidenced by the low P_S indicated. The favorable effect of "4 or more fingers" and the unfavorable effect of "no draws" and "no fingers" is not unexpected due to results of previous analysis. However, observing that the finger and draw factors are not exceptional factors for Class B and Class C suggests that something about the general terrain characterized by the Class A category makes fingers and draws important to navigation performance. Recalling the discussion in the previous paragraph as to what terrain was classified as "1 valley," the results suggest that in Class A terrain, especially in broad depressions (which in this study contained multiple valleys and thus were not classified as 1 valley), routes should be selected to run close to (within 1,000 meters) one side elevation where fingers and draws are visible and not along the center of the depression.

Comparison of interval P_S for all maps with the P_S for the NP-1C map in the general Class A terrain reveals that P_S is about the same when fingers and draws are present. But some property of the NP-1C map permits good performance when fingers and draws (presumably terrain detail) are absent.

The low interval P_S for all maps (general terrain Class A) when "1 or more buildings" are present, may result from a disturbance of the navigator's dark adaptation when building lights are present.

The terrain feature of importance to navigation success in general terrain Class B is "4 or more hills." This result applies to all maps both individually and considered together. Apparently in Class B terrain of multiple hills can be relied on for superior performance.

Water features of importance for both Class B and C are "2 or more ponds" and "no streams." The importance of these factors was discussed in a previous paragraph.

For the Class C terrain and "all maps" as well as the individual map NP-1C, P_S is sensitive to ponds and dams. For all maps,"2 or more ponds" are important to interval P_S while for the NP-1C map "1 pond" is associated with exceptional performance.

ROUTE AND SUBJECT SCORING

METHOD

Analysis of the Independence of Interval Navigation Errors. How can the route P_S be calculated from the interval P_S? If the probability of a navigation error for each route interval is independent of navigation errors for other intervals, then a simple product rule (product of the P_S's for each interval along the route) should yield the correct probability of success for the route. In order to test this calculation rule, which is an application of the binomial theorem, a theoretical prediction was made of the probability of success for a route (probability of exactly no error) along with a prediction of the probability of exactly one error, exactly two errors, etc. The binomial theorem was used for these predictions and the P_S per interval for the theorem was calculated for all subjects on all routes. This theoretical distribution of the number of navigation errors per route was compared with the actual distribution of the number of errors per route.

A chi-square test was used to compare the two distributions. If the two distributions cannot be distinguished, as would be evidenced by a lack of significance of the chi-square test, then the product rule can be accepted as a reasonable way to calculate route P_S.

Calculation of Route P_S. The product rule was used to calculate P_S for each of the four routes. Route P_S was calculated for each of two map categories "all maps" and the NP-1C map. The procedure for assigning P_S to intervals along a route and calculating P_S for that route is as follows:

1. Divide the route into 500 meter intervals.

2. Group intervals into segments according to the PI (1 valley) (valley terrain classification system) described previously. Classify each segment as PI (1 valley) factor Class A, B or C.

3. Select Table 21 and 22 according to map type (If map type NP-1C is to be employed, use data shown in Table 22. If any of the three maps is to be employed, use the data shown in Table 21.

4. For each interval, identify the terrain features present and determine if one or more terrain types is identified as extraordinary in the appropriate table (selected in Step 3 above). If a terrain feature is identified as extraordinary, use the indicated P_S value given in the table for the interval. If no extraordinary terrain feature is present, use the P_S value indicated by the "other terrain types." If more than one terrain feature in an interval is identified as extraordinary, the larger (or largest) indicated P_S is used.

5. After P_S values have been assigned to each interval along a route, the product of the interval P_S values is calculated as the route P_S value.

<u>Calculation of Subject Scores</u>. The purpose of the subject scoring method (SSM) is to provide a weighted score for successful navigation of an interval depending on the terrain features in that interval. Scoring is to be based on the interval P_S achieved at each type of terrain where P_S is determined from the experiment flight data. This provides a general subject scoring method not limited to scoring of performance along routes flown in the experimental flight program.

As an aid in the description of the subject scoring method (SSM), consider all intervals where the probability of success is equal to P_{Si}. Suppose that for each navigation success along those intervals a subject is given an interval score of

$$\frac{1}{P_{Si}} \tag{1}$$

Suppose further that after N_i attempts, a subject has N_{Si} successes at those intervals. The summation of scores for those successes will equal

$$\text{SUM} = \frac{N_{Si}}{P_{Si}} \tag{2}$$

But the probability of success for that subject at those intervals can be defined as

$$P'_{Si} = \frac{N_{Si}}{N_i} \quad \text{or} \quad N_{Si} = N_i \, P'_{Si} \tag{3}$$

Substitution yields

$$SUM = \frac{N_i \, P'_{Si}}{P_{Si}} \tag{4}$$

If the sum is divided by the total number of attempts (N_i) then:

$$\frac{SUM}{N_i} = \frac{P'_{Si}}{P_{Si}} \tag{5}$$

If the subject average performance (P'_{Si}) is equal to the expected performance (P_{Si}), the value of the normalized sum (SUM/N_i) equals 1. If he performs better than expected, his score will be greater than 1, and less than 1 if he does not perform well. Note that the expected P_{Si} is the average P_{Si} over the subjects performing in the experimental flight program.

Of course, the subject scoring method of interest deals with performance in each interval along a route not just in intervals where the P_S equals P_{Si}. If P_{Sj} is now taken to represent the expected probability of success in interval j, then the subject score for a route trial is

$$SCORE = \frac{1}{M} \sum_{j=1}^{N} \frac{k_j}{P_{Sj}} , \tag{6}$$

where

P_{Sj} is the expected probability of success in interval j;

$K_j = 1$ if the student is successful in interval j,

otherwise $K_j = 0$;

N is the number of intervals along the route;

M is the number of intervals attempted.

Note, the expected value of SCORE is obtained if K_j is replaced by the expected probability of success in each interval (P_{Sj}), and therefore, the expected value of SCORE is 1. As a result, a subject performing better than average will achieve a score greater than 1, and less than 1 if he does not perform well.

There is an easier way to calculate scores for a subject. Since subjects experience success in many more intervals than they have errors, it is easier to first compute the score possible if all intervals were completed successfully and then to correct that sum for the navigation errors. The procedure is as follows:

a. Compute the sum of $1/P_{Sj}$ over all route intervals, i.e.,

$$\text{SUM} = \sum_{j=1}^{N} \frac{1}{P_{Sj}} \tag{7}$$

b. If a navigation error occurs, say in interval k, substract the score value for that interval, i.e.,

$$\text{NEW SUM} = \text{OLD SUM} - \frac{1}{P_{Sk}} \tag{8}$$

c. If an interval is missed, say in interval k, subtract 1 from the total interval count and subtract the score values for that interval from the sum, i.e.,

$$\text{NEW N} = \text{OLD N} - 1 \tag{9}$$

$$\text{NEW SUM} = \text{OLD SUM} - \frac{1}{P_{Sk}} \tag{10}$$

d. When all intervals that were missed or that involved navigation errors are processed, the subject's score is computed as

$$\text{SCORE} = \frac{\text{NEW SUM}}{\text{NEW N}} \tag{11}$$

RESULTS

Independence of Interval Navigation Errors. Results of the analysis of the product method of predicting route P_S from component interval P_S(s) is given in Table 25. Since the chi-square test is not significant, there is no reason to believe that the distribution of errors developed by the product rule (binomial theorem) (i.e., probability of exactly no errors, exactly one error, exactly two errors) is different from the distribution observed in the experiment results. This implies that multiple errors on a given route trial can be considered as independent errors. It also implies that the product rule (product of interval P_S's) can be used to predict the route P_S.

Table 25

ANALYSIS OF DISTRIBUTION OF NUMBER OF ERRORS PER ROUTE

	Experiment Data		Binomial Theorem	
Number of Errors	Number of Experiment Trials With Specified Number of Errors	Probability	Probability	Expected Number of Trials
0	11	.141	.151	11.778
1	21	.269	.294	22.930
2	24	.307	.277	21.606
3	14	.179	.168	13.104
4	7	.089	.076	5.928
5	1	.012	.025	1.950
Total	78			

$\chi^2(5) = 1.193,\ p < .05$

Table 26 shows the effect of interval P_S's values on the route P_S value when the product rule is used. As an example, a P_S is calculated for a route containing 30 intervals with each interval having the same P_S. The corresponding value of interval P_S is shown along with the change in route P_S for a .01 change in interval P_S (computed as the derivative of route P_S with respect to $P_S \times .01$). It is shown that the improvement in route P_S increases with increased interval P_S. This result illustrates the importance of interval P_S in achieving high route P_S, and that the relationship is not one of "diminishing returns," but instead, it is one of "increasing returns."

Calculation of Route Probability of Success. Route probability of success values calculated for all maps and for map type NP-1C are shown in Table 27. Route "difficulty" as measured by probability of navigation without error is different for the two map categories. This implies a differential improvement in performance at certain types of terrain with the NP-1C map. The superior performance of subjects using the NP-1C map is demonstrated by the results.

Table 27

ROUTE PROBABILITY OF SUCCESS

Route Number	P_S
All Maps	
1	.097
2	.111
3	.166
4	.176
Map Type NP-1C	
1	.468
2	.224
3	.401
4	.493

Table 26

EFFECT OF AVERAGE INTERVAL P_S ON ROUTE P_S

Average Interval P_S	P_{SR}	Value of Derivative $\left(\frac{d\,P_{SR}}{d\,P_S}\right) \times .01$
.89	.030	.101
.90	.042	.014
.91	.059	.019
.92	.082	.026
.93	.113	.036
.94	.156	.049
.95	.214	.067
.96	.293	.091
.97	.401	.124
.98	.545	.166
.99	.739	.224
.995	.860	.259

P_S is the probability of completing interval without navigational error.

P_{SR} is the probability of completing route without navigational error assuming 30 intervals on the route, i.e., $P_{SR} = P_S^{30}$.

Subject Scores. Subject scores for each route are listed in Table 28. Subjects are grouped according to map type. Average scores for each subject and subject rankings are given in Table 29.

Subjects using the NP-1C maps tend to score high - presumably because of the superiority of the NP-1C map. Score weightings of each interval were based on performances of all subjects and on all routes where all three map types were used. For that reason and the superiority of map NP-1C, subjects using the NP-1C map ranked higher even though they were not necessarily the superior subjects.

DISCUSSION OF THE SUBJECT SCORING SYSTEM

Analysis of the Independence of Subject Errors. Can interval P_S be combined to predict total route P_S? Evidence supporting prediction of route P_S as the product of the component interval P_S(s) is presented in Table 25. Experiment data for all routes are summarized in the lefthand data column. The total of 78 experiment trials resulted in 11 route trials without error, 21 route trials with one error, etc. Probabilities of exactly no errors on a route, exactly one error on a route, etc., calculated from experiment data, are also listed in the table. The corresponding theoretical probabilities and expected number of trials, developed according to the binomial theorem, are also listed. A chi-square test supports the conclusion that the two distributions are not different. Thus it is concluded that prediction of route P_S from interval P_S is feasible using the product rule (the binomial theorem). Also, the expected number of errors per route is predictable using the product rule. It should be emphasized, however, that this conclusion is based on a study of aggregated data for all subjects and all routes. While there is no evidence to the contrary, it is not known if multiple errors by an individual subject along a route can be considered as independent errors.

The effect of average interval P_S on route P_S assuming a 30 interval route is shown in Table 26. The importance of increasing the average interval P_S by .01 on route P_S is listed in the third column. It is seen that payoff for improved interval performance increases the higher the interval P_S. It is also seen that what might seem to be a small difference in P_S at an interval, e.g., Δ = .02 (.94 $\rangle$ .96), provides a substantial difference in route P_S, e.g., Δ = .137 (.156 $\rangle$ .293).

Table 28

SUBJECT SCORES

Subject	Route 1	Route 2	Route 3	Route 4
5	.935	.908	1.030	1.023
6	-	.825	1.030	1.053*
7	1.007	.976	.990	.990
8	1.010	.971	1.030	1.020
17	1.038	1.001	1.028	1.022
18	1.046	1.002	.948	.987
19	.858	.964	1.023	.982
20	.892	.984	.935	.989
SUBJECTS USING MAP TYPE AMD-1B				
9	.985	1.03	.908	.990
10	.808	1.03	.994	.911
11	.890	-	.985	1.053*
12	.868	.968	.826	-
21	1.046	.991	1.030	1.020
22	.965	1.0	.874	.986
23	.971	.943	1.028	.991
SUBJECTS USING MAP TYPE AMD-3A				
13	1.005	.994	1.009	1.022
14	-	.998	1.028	.988
24	1.007	1.060*	.987	-
25	1.084*	.964	1.065*	-
26	1.084*	1.060*	1.065*	1.020
27	1.084*	1.060*	1.065*	1.022
SUBJECTS USING MAP TYPE NP-1C				
Route means	μ = .978	μ = .986	μ = .994	μ = 1.003
Standard deviation of route means	σ = .078	σ = .049	σ = .057	σ = .024

*No errors on flight.

Mean of subject scores - μ = .990
Mean of route mean scores - μ = .990
Standard deviation of subject scores - σ = .057
Standard deviation of route mean scores - σ = .009

Table 29

SUBJECT AVERAGE SCORES AND RANKING

Subject	Number of Flights	Average Score	Rank
5	4	.974	15
6	3	.969	16
7	4	.991	11
8	4	1.008	7.5
17	4	1.022	4.5
18	4	.996	10
19	4	.957	17
20	4	.950	19
SUBJECTS USING MAP TYPE AMD-1B			
9	4	.978	13
10	4	.936	20
11	3	.978	14
12	3	.887	21
21	4	1.022	4.5
22	4	.956	18
23	4	.983	12
SUBJECTS USING MAP TYPE AMD-3A			
13	4	1.008	7.5
14	3	1.005	9
24	3	1.018	6
25	3	1.038	3
26	4	1.057	2
27	4	1.058	1
SUBJECTS USING MAP TYPE NP-1C			

Calculation of Route P_S. The value of the route P_S is obtained by the product of the route interval P_S's which, in turn, are functions of terrain type. Determining interval P_S requires classification of terrain type in two steps. First, the terrain is classified according to the PI (1 valley). This classification is accomplished by dividing the route into segments approximately 3,000 meters in length. The objective is to classify the general terrain over a segment approximately six intervals long (assuming 500 meter intervals). Classification is accomplished by observing the proportion of intervals in 1 valley as follows:

Class	Proportion of Intervals in 1 Valley
A	.00 - .33
B	.34 - .66
C	.67 - 1.00

When the segment is classified, the P_S of each 500 meter interval in that segment is obtained from Table 30. If, for instance, the segment is classified as Class A, the P_S for an interval is .976 unless one or more of the "favorable" or "unfavorable" features, termed special conditions, are in that interval. The existence of a special condition requires selection of a new P_S for the interval according to the values given in the table. And if more than one of the special conditions exist at the interval, then the one with the largest P_S is used. In an example where PI is classified as Class A and an interval contains two fingers, a bridge and no buildings, the P_S would equal .886. Since the interval has two fingers, the first and last conditions are not satisfied. Likewise the second and third conditions are not satisfied leaving only condition four "no draw." If instead there was no bridge, the P_S would be changed to .899. Table 30 provides the P_S for 500 meter intervals and also identifies the cues found to critically affect P_S for each of the three terrain classes.

Instead of computing route P_S by first determining the values for each component interval and then taking the product of interval P_S's, a simplier direct method is available. Tables 31 and 32 provide the route P_S for day (NOE) and night (contour) flights respectively. In each table the ordinate is the length of

Table 30

P_S FOR DOUBLY CLASSIFIED ROUTE INTERVALS
ALL MAPS

Features With Significantly Different P_S	p t-test df = 20	Favorable Feature	Unfavorable Feature
4 or more fingers	.01	.980*	
No bridge	.02		.899
1 or more buildings	.05		.894
No draw	.01		.886
No fingers	.05		.878
P_S for all other features is .976 (18.7% of Class A intervals)			
PI (1 valley) - Class A			
No stream	.001	1.000	
1 or more railroads	.001	1.000	
2 or more ponds	.001	.983	
4 or more hills	.001	.979	
1 or more bridges	.001	.969	
1 or more dams	.01	.962	
P_S for all other features is .883 (14.6% of Class B intervals)			
PI (1 valley) - Class B			
2 or more ponds	.001	.988	
1 or more dams	.001	.983	
P_S for all other features is .931 (83% of Class C intervals)			
PI (1 valley) - Class C			

*Only five intervals

Note: P_S over all intervals without regard to terrain feature is .936.

Table 31

P_S FOR NIGHT NOE NAVIGATION

Total Length of Route (KM)	Length of Route Flown in 1 Valley (KM)										
	0	2	4	6	8	10	12	14	16	18	20
2	.775	.797									
4	.570	.601	.635								
6	.430	.454	.479	.506							
8	.325	.343	.362	.382	.404						
10	.245	.259	.273	.288	.305	.322					
12	.185	.195	.206	.218	.230	.243	.256				
14	.139	.147	.156	.164	.173	.183	.193	.204			
16	.105	.111	.117	.124	.131	.138	.146	.154	.163		
18	.079	.084	.088	.093	.099	.104	.110	.116	.123	.130	
20	.060	.063	.067	.070	.074	.079	.083	.088	.093	.098	.103

Table 32

P_S FOR DAY CONTOUR NAVIGATION

Total Length of Route (KM)	Length of Route Flown in 1 Valley (KM)										
	0	2	4	6	8	10	12	14	16	18	20
2	.715	.745									
4	.512	.533	.555								
6	.367	.382	.397	.414							
8	.262	.273	.284	.296	.308						
10	.188	.195	.203	.212	.221	.230					
12	.134	.140	.146	.152	.158	.164	.171				
14	.096	.100	.104	.108	.113	.118	.122	.128			
16	.069	.071	.074	.077	.081	.084	.088	.091	.095		
18	.049	.051	.053	.055	.058	.060	.063	.065	.068	.071	
20	.035	.036	.038	.039	.041	.043	.045	.046	.048	.050	.053

the total route and the abscissa is the length of the route in 1 valley. These tables provide numerical solutions to the following equations.

$$P_S = .863^{N_V} + .846^{N_N} \text{ for day flight, and}$$

$$P_S = .893^{N_V} + .869^{N_N} \text{ for night flight}$$

where N_V is the length of the segment (in KM) in 1 valley and N_N is the length (in KM) not in 1 valley.

<u>Subject Scoring Method.</u> The subject scoring method (SSM) normalizes interval scores according to historical performance data. This provides an expected score of 1.0 for any route design and any route length - even for a route not previously used.

A student performing as an "average" student will score a value of 1.0 on a route. Superior students or "average" students using superior equipment (such as the NP-1C map) will socre higher than 1.0. Of course, if the superior equipment becomes standard then the reference interval P_S values would be updated so that the expected score would again be 1.0.

The ability of the scoring system to provide a "standard" student evaluation score (i.e., an expected score of 1.0) is evidenced by the mean scores for each route. As shown in Table 28, the mean of the route mean scores is .990 and the standard deviation of the route mean scores is .009. These data support the contention that the student scoring system automatically compensates for differences in route difficulty. The standard deviation for the routes of .009 accounts for both sampling errors and student scoring errors (i.e., error in accounting for differences in route difficulty). That standard deviation is less than the standard deviation of subject scores (.0571). As a result, it appears reasonable to establish a student evaluation system where average students' scores would be .990 $\pm$ .05 independent of route difficulty.

A scoring method, such as the SSM, that provides a higher incremental score for success in intervals with the type of terrain frequently associated with navigation errors would seem to be a useful method. The inverse of interval P_S, i.e., $1/P_S$, indicates the degree of navigation difficulty of an interval which should be taken into account for both route planning and student scoring.

The SSM worked reasonably well in scoring subjects in the experimental program and should be evaluated by instructor pilots. Tables 33 and 34 are scoring aids that might be useful for the instructor. To use the tables, the route the student attempts to navigate must be divided into 500 meter intervals and each interval classified as described in the section "calculation of route P_S." According to that classification, each interval is associated with one 1 valley class and one terrain type (of more than one terrain condition is true at an interval, the condition with the lowest score value is assigned to the interval). The associated score shown in the tables, which equals $1/P_S$, is the score to be assigned to the student for successful navigation of that interval. A "mark" can be placed in the table for each interval navigated successfully. The route score is determined by summarizing the scores for each interval navigated successfully and dividing that sum by the total number of intervals. The value of an average student will be .990 $\pm$ .05. A superior student's score will exceed .995.

It should be noted that the interval P_S values given in the tables for various map and terrain types are actually the P_S per 500 meter interval. If larger intervals are used, such as 1,000 meter intervals, the product rule can be used to calculate the new P_S. For example, if a 1,000 meter interval is used which includes two 500 meter intervals with the same terrain type, then new material P_S = old interval P_S^2.

DAY NAVIGATION ANALYSIS

GENERAL METHOD

Data for the day navigation experiments were recorded in a way similar to that of the night data. Reference routes and the actual subject flight path were marked on maps. Ten different routes were flown with a different set of subjects flying each route. Seven routes were flown by 10 subjects each. Two routes were flown by nine subjects and one route by four subjects. Two different types of maps were used. One map, "PM-50," was used on seven routes. The other map "TM-20" was used on three routes.

Table 33

STUDENT SCORING AID-NIGHT FLIGHT

1 Valley Class

A (0 - 33%)			B (33 - 66%)			C (66 - 100%)		
Terrain Type	Score for 500 Meter Interval	Mark	Terrain Type	Score for 500 Meter Interval	Mark	Terrain Type	Score for 500 Meter Interval	Mark
4+ fingers	1.020		no stream	1.000		2+ ponds	1.012	
no bridge	1.112		1+ railroads	1.000		1+ dams	1.017	
1+ buildings	1.118		2+ ponds	1.017		other	1.074	
no draw	1.128		4+ hills	1.021				
no fingers	1.138		1+ bridges	1.031				
other	1.024		1+ dams	1.039				
			other	1.132				

Note: Mark "√" for a successful interval; "X" for an unsuccessful interval

Table 34

STUDENT SCORING AID - DAY FLIGHT

1 Valley Class

0 - 20%		20 - 40%		40% and Greater	
Score for 500 Meter Interval	Mark	Score for 500 Meter Interval	Mark	Score for 500 Meter Interval	Mark
1.149		1.101		1.030	

Note: Mark " √ " for a successful interval

" X " for an unsuccessful interval

Differences between the day data and the night data included use of a map with 50 foot contour intervals (PM-50), the use of different subjects on different routes, and the use of routes of substantially different length. Also, the set of 45 terrain features previously used (listed in Table 1) was modified. Railroads, rivers, intermittent streams, power lines, and bridges either did not occur at more than a few intervals or were not coded on the maps. Rivers and intermittent streams were considered to be included with streams on the map. Table 35 lists the terrain feature types with notation regarding the day navigation data. Table 36 provides a tabulation of the differences between the night and day navigation data.

The effect of the 50 foot contour intervals on map PM-50 caused difficulty in identifying terrain features. It is believed that some hills were not detected and an accurate count of terrain fingers and draws was not obtained. Review of terrain coding showed that some valleys may have been coded as draws. Because of this probability, draw coding was reviewed and draws were divided into two categories - major and minor draws. Minor draws are draws that have a floor length of 250 to 1,000 meters while major draws are from 1,000 to 2,500 meters in length.

Because the night navigation experiments used the same set of subjects over all four routes, a repeated measure analysis was used. This method employed differences in subject scores for different routes, and different types of terrain. In order to employ a similar methodology for the day navigation data, subjects were paired according to overall performance on each route. For example, the best performer on one route was paired with the best performer on each of the other routes. Accordingly, 10 composite "subjects" were identified on six routes of approximately the same length. Table 37 documents the matched subjects identification. Route numbers 2, 4, 10, 11, 12 and 14 were selected for detailed analysis. Data from the seventh route, also performed by 10 subjects, were not used because that route was considerably longer than the other routes.

Terrain features along the six routes were coded using the same feature identification criteria employed for the night data. However, these data were not entered into the computer but were instead listed in charts for hand analysis. The simplified hand analysis was selected because time did not permit coding of all the terrain feature parameters coded with the night data. Much

Table 35

EXPANDED FEATURE CLASSES WITH NOTATION FOR DAY DATA

Class ID Number	Type of Terrain Feature	Number of Features in Class	Notation
1	Ridge	None	
2	Ridge	1 or more	
3	Hill	None	
4	Hill	1, 2, or 3	
5	Hill	4 or more	
6	Finger	None	
7	Finger	1, 2, or 3	
8	Finger	4 or more	
9	Valley	None	
10	Valley	1 Only	
11	Valley	2 or more	
12	Draw	None	
13	Draw	1, 2, or 3	
14	Draw	4 or more	
15	Plateau	None	
16	Plateau	1 or more	
17	Rivers	None	Did not exist in any interval
18	Rivers	1 only	
19	Rivers	2 Only	
20	Stream	None	
21	Stream	1 or 2	
22	Stream	3 or more	
23	Int. Stream	None	Not coded on map PM-50
24	Int. Stream	1 or 2	
25	Int. Stream	3 or more	

Table 35 (Concluded)

EXPANDED FEATURE CLASSES WITH NOTATION FOR DAY DATA

Class ID Number	Type of Terrain Feature	Number of Features in Class	Notation
26	Pond	None	
27	Pond	1 Only	
28	Pond	2 or more	
29	Highway	None	
30	Highway	1 or more	
31	Road	None	
32	Road	1 or 2	
33	Road	3 or more	
34	Railroad	None	Occurred in only one interval
35	Railroad	1 or more	
36	Building	None	
37	Building	1 or more	
38	Developed Area	None	
39	Developed Area	1 or more	
40	Power line	None	Did not exist in any interval
41	Power line	1 or more	
42	Dam	None	
43	Dam	1 or more	
44	Bridge	None	Not coded on map
45	Bridge	1 or more	

Table 36

DIFFERENCES BETWEEN DAY AND NIGHT NOE DATA

Item	Night Navigation Data	Day Navigation Data
1	One area of operation	Three areas of operation
2	Four routes	Ten routes
3	Three map types	Two map types
4	All maps 20 feet contour	One map with 50 feet contour
5	More rugged terrain, greater elevation difference	--
6	Matched subjects design of the experiment	Random selection of subjects
7	Terrain coded as a composite of all three map types	Single maps used for terrain coding
8	--	No intermittent streams and rivers coded
9	Greater number of different features - railroads, power line, bridge were included	Same features did not occur
10	Plateau - wide flat area to side of wide valley	Plateau - more like a ridge
11	Less ridges coded	More ridges because of 50 feet contour lines on map

Table 36 (Concluded)

DIFFERENCES BETWEEN DAY AND NIGHT NOE DATA

Item	Night Navigation Data	Day Navigation Data
12	More hills detected and coded	Fewer hills detected and coded
13	Average route length 16 Km	Shorter average route length = 10.5 Km
15	Draws defined as less than 2,500 meters in length	Minor draw defined as 250 to 1,000 meters long. Major draw defined as 1,000 to 2,500 meters long
16	Four routes coded	Six routes coded
17	--	More developed areas, more intervals involving buildings

Table 37

MATCHED SUBJECTS - DAY NOE

Composite Subject Number	Route 3	Route 4	Route 10	Route 11	Route 12	Route 14
	Subject on Routes					
1	3	4	6	1	2	6
2	10	9	7	2	4	2
3	1	6	3	3	5	7
4	2	7	10	5	6	1
5	7	10	2	6	9	4
6	8	5	8	4	7	5
7	9	8	9	8	8	8
8	4	1	1	9	10	3
9	6	2	4	10	1	10
10	5	3	5	7	3	9

of the night parameter data that were coded were not used in the night data analysis. Thus, a similar analysis could be applied to the day data with a simplified coding of data. In order to simplify the hand analysis, 1,000 meter intervals were used instead of the 500 meter intervals used for the night data analysis.

Analysis M: Calculation of the Probability of Success P_S in Intervals Classified by a Single Terrain Feature Type.

METHOD. Intervals classified by the reduced number of terrain feature types were searched in a manner similar to that of night data Analysis A. This method uses test of the differences in interval P_S as a function of the number of terrain features of a given type. For example, interval P_S for "no ponds" was compared to the P_S for "1 pond" and then to the P_S for "2 or more ponds." A Wilcoxon test was used to determine the significance of differences in P_S.

RESULTS. Tests of the significance of the number of terrain features of a given type showed that changes in the number of terrain features did not have a significant effect on interval P_S.

Analysis N: Prediction of Route P_S as a Function of the General Terrain Type Along the Route.

METHOD. This analysis corresponds to Analysis D as applied to the night navigation data. The proportion of intervals along a route associated with a given route is used as the independent variable in a regression analysis. Composite P_S for a route is the dependent variable where route composite P_S was computed as the number of successfully completed route intervals (without error) divided by the number of intervals attempted. An F test was used to determine the significance of the regression function.

RESULTS. Results of the regression analysis showed that the proportion of intervals associated with "1 valley" or "1 major draw" (but not both) is significantly related to the route composite P_S, $F(1,4)$ 46.41, $p \leq .005$. Table 38 lists the data and regression results.

Table 38

REGRESSION ANALYSIS RESULTS

Route Number	Composite P_S For Route	Proportion of Intervals Associated With One Valley or One Major Draw
11	.942	.428
12	.884	.400
10	.849	.300
3	.826	.250
4	.758	.000

$F(1,4)\ 46.41,\ p \leq .005$

Analysis O: Effect of Route Geometry on Interval P_S.

METHOD. Analysis O is an analysis of the effect of route geometry on interval P_S. P_S for intervals involving route heading changes greater than 5^o and heading changes greater than 30^o was compared to the P_S for intervals involving no heading changes. Data was completed for each of the six routes and a Wilcoxon test was used to test the significance of interval P_S differences.

RESULTS. Results show that route geometry does significantly affect interval P_S. All heading changes greater than 5^o result in a reduced interval P_S (.928 for straight intervals versus .812 for intervals involving heading changes), (χ^2 (1) = 20.5, $p \leq .005$). A similar result shows a reduced P_S for intervals involving large heading changes (greater than 30^o) (.928 for straight intervals versus .815 for intervals involving large heading changes), (χ^2 (1) = 13.9, $p \leq .005$).

Discussion of Day Navigation Data. The lack of a significant effect of the number of terrain features in intervals on interval P_S represents a difference in the result of the day and night data analysis. It is not known if this result is due to true effects of day navigation performance or reflects the difficulties experienced in coding maps with 50 foot contour intervals.

Prediction of route composite P_S as a function of general terrain type, i.e., proportion of intervals involving one valley or one major draw was significant and is consistent with the results found in the night data. Apparently, the existence of a single valley defines a fundamental type of terrain which is significant to navigation performance.

The concept that route geometry affects performance was demonstrated with both the day and night data. The reduction in interval P_S from .928 to .812 represents an important factor in route P_S and thus should be considered in route planning. The sizes of the turn may be a significant factor but this factor was not analyzed.

CONCLUSIONS

1. Of the 45 terrain factors tested, one terrain factor was found to be the most significant single factor for predicting route probability of success P_S. This factor is PI (1 valley) - the proportion of the route in one valley. It is an important factor for selecting routes, identifying cues along a route, and evaluating the expected P_S along a route for both day and night navigation.

2. The factor PI (1 valley) is positively correlated with P_S; the condition V_T (route is in a valley) is negatively correlated with P_S. This difference emphasizes that performance is enhanced not by simply placing the route in a valley, but that the valley must have certain properties.

   a. The valley must be narrow (most important) and there must not be other "valley like" depressions in the immediate area.

   b. Draws must be easily distinguished from "other valley like" depressions. This can be done by observing that draws have rapid elevation to the horizon sufficiently close to the flight path (say within 1,000 meters) to permit the navigator to easily identify the draw. Otherwise, the depression is "valley like" - a condition where navigation errors are likely.

3. The navigator, if working with a fixed route plan, should pick cues as a function of terrain classified by PI (1 valley) and seek redundant cues where detrimental terrain influences exist.

4. The existence of multiple terrain features such as two or more ponds, four or more fingers, four or more draws, tends to improve interval P_S significantly. Also, there is no "magic" about the specific number. For example, there is an increasing P_S associated with one finger, two fingers, ..., seven fingers and it appears that at the level of four or more fingers, the results become significant at the statistical confidence level selected.

5. Two combinations of terrain factors and route geometry lead to navigation errors and explain a large percentage of P_S variance. These combinations are "a wide valley and a route heading change" and "a wide valley and the existence of other 'valley like' depressions in the area."

6. The "route not in a valley, no heading changes, and no other depressions in the area" is positively correlated with P_S and explains 99.8 percent of the P_S variance over full routes.

7. Ambient light level does not appear to affect P_S.

8. The mere existence of one or more clearings does not appear to affect P_S. There is some evidence to support the concept that performance improves where there are clearings that are distinct from one another. This supports the hypothesis that clearings are used as dividers separating possible route paths. An alternative concept that clearings with a unique shape are used as location identification cues could not be tested because "unique shape" was not defined.

9. There is little question that map type NP-1C which was used for the night navigation experiments supports superior performance.

10. The 50 foot contour intervals on map type PM-50 caused considerable difficulty in identifying terrain features for the study. It is suspected that the navigator would also have difficulty in using that map for the same reason.

11. P_S for a route or route segment can be obtained by the product of P_S for the component intervals.

RECOMMENDATIONS

The P_S's calculated for various terrain types reveal the expected navigation error rates for each type of terrain. These P_S values should be used in route planning (to select the

route with least probability of error), and cue selection (to look for redundant cues in situations where errors are likely, i.e., P_S is low). Further, the P_S performance information should be supplied to students in the classroom so they can become familiar with navigation error rates associated with specific types of terrain. A method of computing route on interval P_S is given in the section "Calculation of Route P_S" (page 60).

A navigator planning his navigation strategy should select his terrain cues based on the terrain classification according to PI (1 valley) because the important local terrain features are different depending on the type of terrain as classified by the PI (1 valley) factor. For example, if a route segment has a low value of PI (1 valley), the existence of "4 or more fingers" can significantly improve route segment P_S; and further, the existence of one or more buildings or the absence of any fingers and draws can significantly decrease route segment P_S. In contrast, consider a route segment where PI (1 valley) is high. In that case, the existence of multiple fingers or buildings do not seem to be important to segment P_S; but, the existence of two or more ponds can significantly improve route segment P_S. Thus the navigator, if working with a fixed route plan, should pick cues as a function of terrain classified by PI (1 valley) and seek redundant cues where detrimental terrain influences exist.

The normalized student scoring method (SSM) appears to be a useful scoring concept which should be presented to and evaluated by IP's in field trials. Evaluation of the method can be accomplished from IP's comments. It may be desirable to expand the scoring rule to account for the size of each error. A method of computing student scores is given in the section "Subject Scoring Method" (page 64).

Differential performance as a function of terrain type was obtained with different map types. This suggests that each map type may be beneficial in different ways. For example, the NP-1C map supported best overall performance; but, with that map, the existence of one or more buildings tends to reduce the P_S. Presumably, lights from the buildings, at night, affect the navigator's dark adaptation. The question is: did the same effect appear with the other map types? Why didn't the building appear as a statistically significant factor for the other types of maps? Studies of selective differences among the maps may provide specifications for a composite map that is more useful than the component maps used in the experiments.

The 50 foot contour intervals on map type PM-50 caused considerable difficulty in identifying terrain features such as hills, ridges and fingers for the study. It is suspected that the navigator would also have difficulty in using that map for the same reason. In contrast, maps with 20 foot contour intervals permitted identification of the required terrain features.

The use of logical (Boolean) combinations of terrain and route geometry provided a sensitive measure of different factor combinations without requiring many replications of experiment trials (only four routes were used in the night experiment). The method appears to have potential in empirical investigations.

Finally, correlation analysis among terrain and route geometry conditions showed that several conditions were highly correlated. This high correlation is due to the route design and prevented investigation of the effect of the individual conditions on route P_S. While it is recognized that it is difficult to identify all important factors prior to conducting an experiment, it is worthwhile to evaluate correlations among experiment conditions prior to conducting the experiment to insure that important conditions are not highly correlated by the experiment design.

APPENDIX A
METHODS FOR REPRESENTING ELEVATION AND TERRAIN FEATURES ALONG AN NOE ROUTE

INTRODUCTION

A first step in the analysis of NOE navigation error patterns and the development of a NOE navigation performance measure is the coding of terrain cues along NOE routes. Features coded are those suspected of being used as navigation cues. The terrain coding used is described in this appendix. The features to be used are identified in the following section and where necessary, definitions are provided. Parameters used to further categorize each feature are also identified in this section. The system for coding the location of a feature is presented in the section entitled "Feature Location." The final section, "Route Coding," deals with the organization of coded information, representing each NOE route, for computer input.

FEATURES AND ASSOCIATED PARAMETERS

Information on the maps is organized in four categories: elevation, terrain (vegetation, hydrography), and man-made. Elevation features are defined in Table 1. The terrain features (vegetation, hydrography, man-made) of interest are defined to be consistent with those of the maps, however some differences exist. Table 2 provides a listing of candidate terrain features with definitions as necessary.

Associated with each feature are parameters which are modifiers further describing feature characteristics. Table 3 specifies the parameters for each feature and Table 4 details the unit of measurement for each parameter.

SIZE PARAMETERS

The size of elevation features is defined by the following measures:

Ridge	Distance along ridge top Distance from top to base

Table A1

NAMES ELEVATION FEATURE

Hill	A rounded elevation
Ridge	A range of hills or mountains
Finger	A lesser elevation extending from a ridge
Saddle	An elevation depression connecting two higher points
Valley	A long wide depression between a range of hills or mountains
Draw	A narrow depression between fingers or ridges
Floor	The low flat area of a valley
Plateau	A large flat land area elevated above adjacent land on at least on side

Table A2

TERRAIN FEATURE NAMES

Name	Map Symbol
Dense woods	*
Woods	*
Scattered trees	*
Orchard	*
Marsh	*
Scrub	*
Cultivated	*
Clearing	*
River	River is identified by a double line on the map
Stream	Stream is identified by a single or broken line on the map
Pond	Any enclosed body of water
Highway	Any road, two or more lanes, medium duty or greater
Road	Dirt or improved light duty road
Railroad	*
Building(s)	Any type of building
Developed area	Ten or more buildings in a group
Towers	Any man-made development not otherwise specified here (e.g., antennas, silo, light or microwave tower)
Bridge	Any bridge
Dam	Any dam
Power transmission lines	*
water tanks	*

*Definition consistent with a composite of symbols defined on map types "Air Movement Data Experimental Prototype #B," "Experimental Air Movement Data Red-Light Night-Use Prototype #3A," and Experimental Night Prototype #1C."

Table A3

FEATURE PARAMETERS CODED

Elevation and Terrain Features	Parameters Coded 1	2	3	4	5	6	7	8	9	10
Ridge	×	×	×			×	×	×		
Hill	×	×	×			×	×			
Finger	×	×				×	×	×		
Saddle	×	×			×	×	×			
Valley	×	×			×			×		
Draw	×	×						×		
Floor	×	×			×					
Plateau	×	×	×							
Dense woods	×	×						×	×	
Woods	×	×						×	×	
Scattered trees	×	×						×	×	
Orchard	×	×						×		
Marsh	×	×						×		
Scrub	×	×						×		
Cultivated	×	×						×		
Clearing	×	×						×		
River								×		
Stream								×		
Pond	×	×		×						
Highway				×				×		
Road				×				×		
Railroad								×		
Buildings										×
Developed towers			×	×						×
Bridge								×		
Dams								×		
Power lines								×		
Water tanks			×	×						

(1) Size
(2) Shape
(3) Maximum elevation
(4) Elevation
(5) Minimum elevation
(6) Type of Slope
(7) Amount of Slope
(8) Orientation
(9) Type of Woods
(10) Light Beacon

Table A4

UNITS OF MEASUREMENT FOR FEATURE PARAMETERS

Size	Meters or square meters
Shape	Name, ratio or percent of dimensions
Elevations	Feet from sea level
Slopes	Name types of slope and average amount in degrees
Orientation	Categories 1. N-S 2. NNE - SSW 3. ENE - NSW 4. E - W 5. ESE - WNW 6. SSE - NNW
Type of Woods	Deciduous or coniferous
Light Beacon	Yes or No

Hill	Distance from base to top Distance from base to base
Finger	Distance from base to top Distance between top of draw on each side
Draw	Distance from tops of fingers on each side Distance from base to top
Valley	Distance measured at right angle to route direction between two highest points Distance in line-of-sight along length
Saddle	Distance from low point to high point Distance from low point to other high points
Floor	Length and width of flat area
Plateau	Length and width of flat area

The size of vegetation and ponds is represented by the areas portrayed on the maps.

SHAPE PARAMETER

Elevation Features

Ridge	The number of high and low points within 1,000 meters of a reference point (see section "Feature Location" for discussion of points along the route). Another shape representation of a ridge is the ratio of length of width
Hill	Ratio length to width
Finger	Ratio of length to width

	Shape of finger tip requires classification but a recommended method has not been determined at this time.
Saddle	The ratio of smaller peak to large peak expressed as a percent
Valley	Classify as "U" or "V" shapped
Draw	Ratio length to width
	Classify as "U" or "V" shapped
Floor and Plateau	Ratio length to width
Vegetation	The longest dimension and the percent of width to longest dimension
Ponds	The longest dimension and the percent of width to longest dimension

ELEVATION PARAMETERS

Table 3 defines the elevation measure for specific features.

SLOPE PARAMETERS

Slopes are classified in three categories as follows:

1. Uniform
2. Convex
3. Concave

Slope is also represented by its steepness angle.

ORIENTATION PARAMETER

Orientation of a feature is the angle between its long axis (if one exists) and North. Orientation of an edge of a feature is the angle between that edge and North.

TYPE OF WOODS

Trees are classified into two types: deciduous and coniferous.

LIGHT BEACON PARAMETER

A man-made feature known to provide a source of light at night (e.g., beacon tower, town).

FEATURE LOCATION

Prior to terrain coding, each route was divided into intervals 500 meters (1,000 meters for day data) in length. The center of each interval is used as a reference point for the interval.

The location of a feature relative to an interval reference point is coded using a polar overlay containing a grid as shown in Figure 1. The relative location of a feature is recorded according to the grid cell (or cells) which contains the feature. The polar overlay divides the area around the reference point into eight bearing and four range segments.

ROUTE CODING

Information recorded for each interval reference point includes:

Route number

Reference point sequence number

Heading to next point

Distance to next point

Route elevation

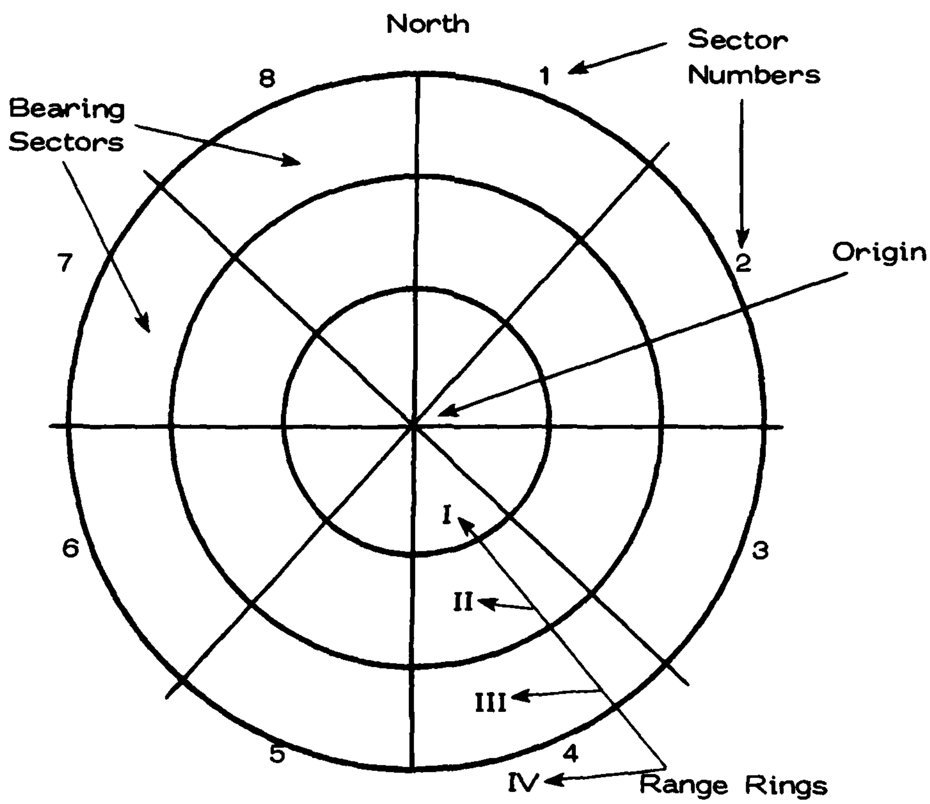
Primary vegetation in area

Number of terrain and elevation features

Figure A1

POLAR OVERLAY "STAR CODE"

Eight sectors of
45° each



Range Ring Radius Dimensions

I	250 meters
II	500 meters
III	1000 meters
IV	greater than 1000 meters

For each feature identified within the overlay area, its name, location, and other parameters are coded. Table 5 defines the code number for each type of feature.

The method of coding the location of a feature with respect to an interval reference point is accomplished as follows:

1. Identify the next interval reference point along the route.

2. Place origin of overlay on reference point maintaining North orientation.

3. Determine and record the sections containing each feature.

A binary code is used to identify the combination of sectors containing a feature. As an example, assume that a feature is contained in sectors one, three, and four and range rings one and two. The sector code is equal to

$$9 = 2^{0}\text{(for sector one)} + 2^{1}\text{ (for sector two)}$$

$$+ \; 2^{3}\text{ (for sector four)}$$

The range code for a feature in range sectors one and two is computed in a similar way:

$$3 = 2^{0}\text{ (for sector one)} + 2^{1}\text{ (for sector two)}$$

Table A5

FEATURE NAME CODES

Feature Name	Code
Elevation	
Ridge	10
Hill	11
Finger	12
Saddle	13
Valley	14
Draw	15
Floor	16
Plateau	17
Vegetation	
Dense woods	20
Woods	21
Scattered trees	22
Orchard	23
Marsh	24
Scrub	25
Cultivated	26
Clearing	27
Hydrology	
River	30
Stream	31
Pond	32
Man-Made	
Highway	40
Road	41
Railroad	42
Building	43
Developed area	44
Tower	45
Water tank	46
Power transmission lines	47
Dams	48
Bridges	49

APPENDIX B
COMPUTER PROGRAM DOCUMENTATION FOR THE ANALYSIS OF NIGHT TACTICAL NAVIGATION DATA

INTRODUCTION

The computer programs documented herein can search, under user control, data files containing night tactical helicopter navigation data. The purpose of the programs is to permit search of the navigation data file to locate terrain of a specified type and to determine the number of successful and unsuccessful attempts to navigate that type of terrain. The terrain type is specified by the user. Output of the programs consist of printout revealing the number of subject navigator attempts, successes and probability of success (P_S) for each subject and each route.

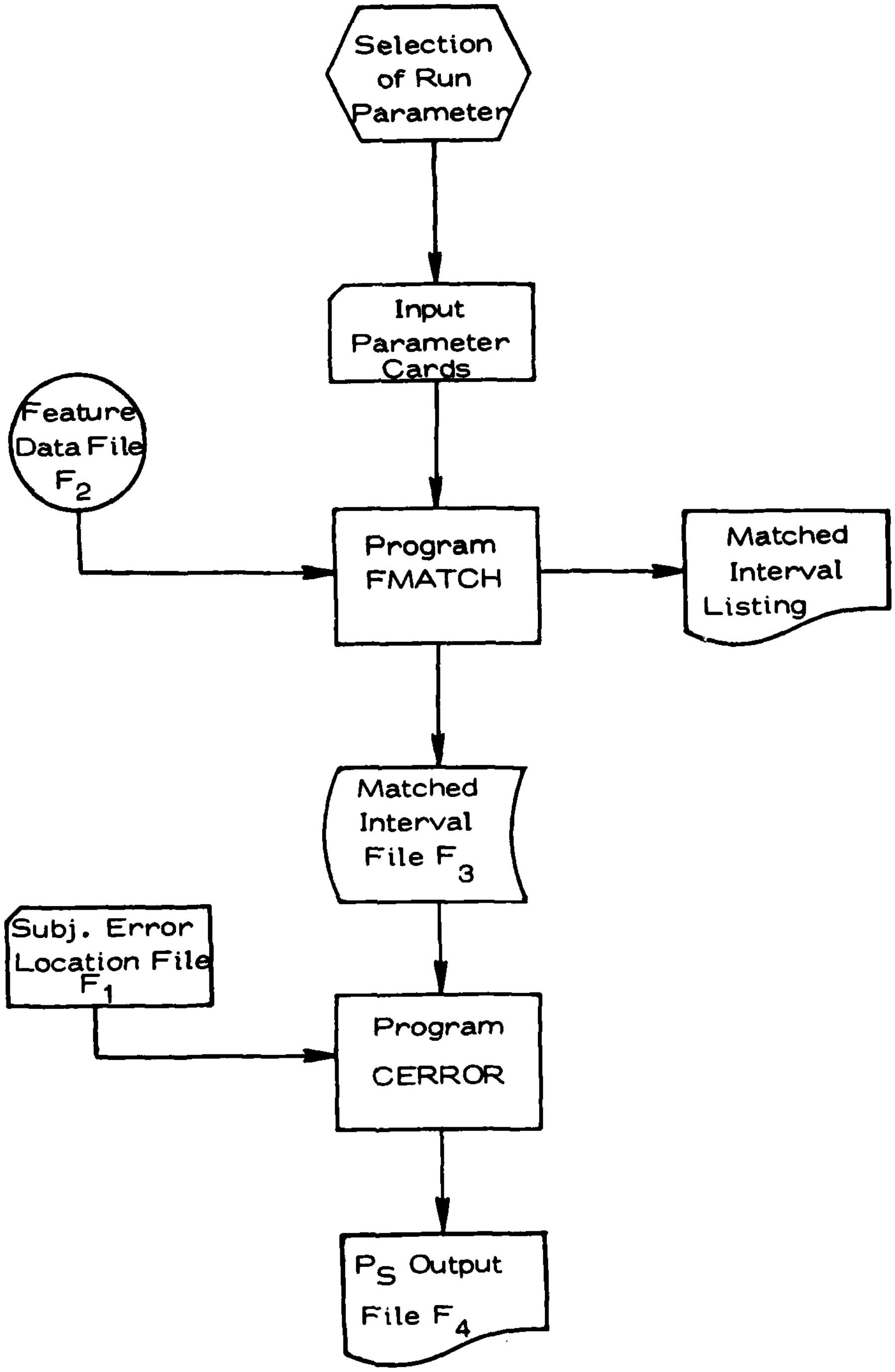
Associated with the computer programs are: a data file which contains terrain data (on magnetic tape), input cards which are punched by the user to specify the type of terrain features of interest, input cards which identify location of subject navigation errors, and job control language (JCL) cards which provide instructions to the computer for running the programs.

Figure 1 is a flow diagram for the system. In using the system, the user selects terrain features and feature parameters of interest, and prepares "input parameter cards" representing the desired terrain features. These cards are the only input required by the user.

JCL cards, input parameter cards, subject error location cards, and program cards are input to the computer. Proper ordering of the cards is described in a subsequent section. Once the cards are input all data search calculations are automatic including generation and reading of the intermediate file "matched interval file." The computer produces the desired output printout. Each of the card systems, files, output and programs are documented in the following sections.

Figure B1

SYSTEM FLOW DIAGRAM



INPUT CARDS

TERRAIN FEATURES AND FEATURE PARAMETERS

The first terrain feature card specifies valley and clearing classifications (see final report for discussion of valley classes A, B, C). This card must be included in each run.

Additional terrain cards are used to specify the terrain type of interest. Two cards (a set) are used to specify each terrain feature to be included or excluded in the search. Up to 50 terrain feature cards (i.e., 50 sets of cards) can be specified; but, at least one set must be included.

Formats for these cards are as follows:

Valley and Clearing Class Card Format

Search Parameter	Input Values	Format
1. Valley class*	0,1,2,3	I5
2. Clearing class**	0,1,2	I5

*Class 0 includes all intervals
1 includes only intervals in Class A
2 includes only intervals in Class B
3 includes only intervals in Class C

**Class 0 includes all intervals
1 includes only intervals with no clearing
2 includes only intervals with clearings

Card 1 Format is 2I5

Terrain Feature and Feature Parameter Card Formats*

CARD #1

Search Parameter	Input Values	Item#	Card Column
1. Feature type	Number code for feature (Table 1)	1	1 - 5
2. Match code	1, -1 **	2	6 - 10
3. Minimum number of features required for pattern match	Integer ≥ 0	3	11 - 15
4. Maximum number of features required for pattern match	Integer ≥ 0	4	16 - 20
5.	Blank	5	
	Blank	6	
	Blank	7	
6. Range			
A. Zone 1	1, -1 **	8	36 - 40
B. Zone 2	1, -1	9	41 - 45
C. Zone 3	1, -1	10	46 - 50
7. Orientation			
A. N-S	1, -1 **	11	51 - 55
B. NNE-SSW	1, -1	12	56 - 60
C. ENE - WSW	1, -1	13	61 - 65
D. E-W	1, -1	14	66 - 70
E. ESE-WNW	1,-1	15	71 - 75
F. SSE-NNW	1, -1	16	76 - 80

Search Parameter	Input Values	Item #	Card Column
CARD #2			
8. Length of Features (meters)			
A. Minimum length of feature for pattern match	Integer ≥ 0	17	1 - 5
B. Maximum length of feature for pattern match	Integer ≥ 0	18	6 - 10
9. Width of Features (meters)			
A. Minimum width of feature for pattern match	Integer ≥ 0	19	11 - 15
B. Maximum width of feature for pattern match	Integer ≥ 0	20	16 - 20
10. Elevation of Features (feet above sea level)			
A. Minimum elevation of feature for pattern match	Integer ≥ 0	21	21 - 25
B. Maximum elevation of feature for pattern match	Integer ≥ 0	22	26 - 30
11. Vegetation (for elevation features only)	Ø for all types of vegetation or vegetation code	23	31 - 35
12. Finger Elevation Change			
A. Minimum elevation change for pattern match	Integer ≥ 0	24	36 - 40
B. Maximum elevation change for pattern match	Integer ≥ 0	25	41 - 45
13. Finger Elevation Change Type			
A. Uniform	1, -1 **	26	46 - 50
B. Convex	1, -1	27	51 - 55
C. Concave	1, -1	28	56 - 60
D. Compond	1, -1	29	61 - 65

*Format for all items is I5, Card 2 format is 16I6, Card 3 format is 13I5

**1 = include feature

-1 = exclude feature

Table B1

LISTING OF TERRAIN FEATURES

Class ID Number	Type of Terrain Feature	Number of Features in Class
1	Ridge	None
2	Ridge	1 or more
3	Hill	None
4	Hill	1, 2, or 3
5	Hill	4 or more
6	Finger	None
7	Finger	1, 2, or 3
8	Finger	4 or more
9	Valley	None
10	Valley	1 Only
11	Valley	2 or more
12	Draw	None
13	Draw	1, 2, or 3
14	Draw	4 or more
15	Plateau	None
16	Plateau	1 or more
17	Rivers	None
18	Rivers	1 Only
19	Rivers	2 Only*
20	Stream	None
21	Stream	1 or 2

*More than two never occurred in an interval

Table B1 (Concluded)

LISTING OF TERRAIN FEATURES

Class ID Number	Type of Terrain Feature	Number of Features in Class
22	Stream	3 or more
23	I. Stream	None
24	I. Stream	1 or 2
25	I. Stream	3 or more
26	Pond	None
27	Pond	1 Only
28	Pond	2 or more
29	Highway	None
30	Highway	1 or more
31	Road	None
32	Road	1 or 2
33	Road	3 or more
34	Railroad	None
35	Railroad	1 or more **
36	Building	None
37	Building	1 or more
38	Dev. Area	None
39	Dev. Area	1 or more **
40	Power Line	None
41	Power Line	1 or more **
42	Dam	None
43	Dam	1 or more
44	Bridge	None
45	Bridge	1 or more

**More than one never occurred in an interval

SUBJECT ERROR LOCATION (F_1)

The subject error location file has been prepared and need only be input with each computer run. Two types of cards are used: one (Type 1) specifying the number of errors and missed route intervals along a route for each subject and the other card (Type 2) identifying the location of each navigation error. Formats for these cards are as follows:

CARD TYPE #1 (One card per subject per route)

Item	Format	Card Column
1. Error Summary		
A. Route number	I5	1 - 5
B. Subject number	I5	6 - 10
C. Attempt code*	I5	11 - 15
D. Number of errors on route	I5	16 - 20
E. Number of misses on route	I5	21 - 25
CARD TYPE #2 (One card per error or missed interval)		
2. Error Summary		
A. Flag**	I5	1 - 5
B. Location(elapsed meters on route)	I5	6 - 10

*-1 if subject did not attempt route, otherwise entry should be 1
**Flag 0 if miss, 1 if error

FILE FORMATS

Formats for three files: terrain feature data file (F_2), matched interval file F_3, and P_S output file F_4 are given in Tables 2, 3, and 4 respectively.

JOB CONTROL LANGUAGE

The JCL required to run the program is listed in Table 5.

PROGRAM OUTPUT FORMAT

A sample program output reflecting example data is given in Table 6.

PROGRAM LISTING

A listing of the computer programs is given in Table 7.

Table B2

TERRAIN FEATURE DATA FILE

Item	Format
(1) Formats for feature interval definition	
1. Route number	I3
2. Sequence number	I3
3. Distance from sequence number point	I5
4. Lower boundary of interval*	I7
5. Upper boundary of interval*	I7
6. Number of possible elevation features	I3
7. Number of possible man-made features	I3
8. Number of possible water features	I3
(2) Elevation Features	
1. Route number	I3
2. Sequence number	I3
3. Feature type	I3
4. Center location, X coordinate**	I4
5. Center location, Y coordinate	I4
6. Length	I5
7. Width	I5
8. Slope type	I4
9. Slope amount	I4
10. Associated vegetation	I4
11. Orientation	I4
12. Elevation	I4
13. Bearing at sequence number	I4
14. Range at sequence number	I4
15. Bearing at next sequence number	I4
16. Range at next sequence number	I4
17. Bearing from interval midpoint	I4
18. Range from interval midpoint	I4

*Elapsed meters on route path

**Center location is found at the first point from which a feature is coded and except for hills, fingers, bridges, dams, ponds, they do not represent the actual location of the feature.

Table B2(Concluded)

TERRAIN FEATURE DATA FILE

Item		Format
(3)	Man-made Features	
1.	Route number	I3
2.	Sequence number	I3
3.	Feature type	I3
4.	Center location, X coordinate	I4
5.	Center location, Y coordinate	I4
6.	Orientation	I4
7.	Bearing at sequence number	I4
8.	Range at sequence number	I4
9.	Elevation	I4
10.	Bearing at next sequence number	I4
11.	Range at next sequence number	I4
12.	Bearing from interval midpoint	I4
13.	Range from interval midpoint	I4
(4)	Water Features	
1.	Route number	I3
2.	Sequence number	I3
3.	Feature type	I3
4.	Center location, X coordinate	I4
5.	Center location, Y coordinate	I4
6.	Orientation	I4
7.	Bearing at sequence number	I4
8.	Range at sequence number	I4
9.	Length	I4
10.	Width	I4
11.	Elevation	I4
12.	Bearing at next sequence number	I4
13.	Range at next sequence number	I4
14.	Bearing at interval midpoint	I4
15.	Range at interval midpoint	I4

Table B3

FORMAT OF "MATCHED INTERVAL FILE"

	Item	Format
1.	Route number	I6
2.	Sequence number	I6
3.	Distance from sequence point	I6
4.	Lower boundary of interval	I6
5.	Upper boundary of interval	I6

Table B4

FORMAT FOR P_S OUTPUT FILE

	Item	Format
1.	P_S Route 1	F7.3
2.	P_S Route 2	F7.3
3.	P_S Route 3	F7.3
4.	P_S Route 4	F7.3
5.	P_S Route 5	F7.3

Table B5

SYSTEM JCL

```
//STI1 EXEC FORTCLG
//FORT.SYSIN DD *
//*       PROGRAM FMATCH
//*       PRINTER
//GO.FTO6F001 DD SYSOUT = A
//*       INTERVAL FEATURE FILE
//GO.FT02F001 DD DSN=RINF,DISP=(OLD,KEEP),
// UNIT=TAPE9,VOL=SER=NTNOE,LA3EL=1,
// DCB=(RECFM=FB,LRECL=120,BLKS12E=18000)
//*       MATCHED INTERVAL FILE
//GO.FT03F001 DD DSN=RMAT,DISP=(NEW,PASS),
// UNIT=SYSDA,SPACE=(TRK,200),
// DCB=(RECFM=FB,LRECL=30,BLKSIZE=4500)
//*       INPUT PARAMETER FILE
//GO.FT01F001 DD *
//*       DELETE FIRST PROGRAM
//ST2 EXEC PGM=IEFBR14
//DD1 DD DSN=&LOADSET,UNIT=SYSDA,
// DISP=(OLD,DELETE)
//ST3 EXEC FORTGLG
//FORT.SYSIN DD *
//*       PROGRAM CERROR
//*       PRINTER
//GO.FTO6F001 DD SYSOUT=A
//*       MATCHED INTERVAL FILE
//GO.FTO1F001 DD DSN=RMAT,DISP=(OLD,DELETE),
// UNIT=SYSDA
//*       SUBJECT ERROR LOCATION FILE
//GO.FT02F001 DD *
//*       SUBJECT PS FILE
//GO.FT03F001 DD DSN-SUBPS,UNIT=SYSDA,
// DISP=(NEW,PASS),SPACE=(TRK,100),
// DCB=(RECFM=F,LRECL=35,BLKS12E=35)
```

IBM (360/50)

Table B6

SAMPLE PROGRAM OUTPUT

COUNT OF ATTEMPTS (A) AND SUCCESSES (S) FOR DEFINED PATTERN

NUMBER OF INTERVALS
ROUTE#1 29
ROUTE#2 38
ROUTE#3 31
ROUTE#4 34
ALL 132

SUB	ROUTE#1 S	ROUTE#1 A	ROUTE#2 S	ROUTE#2 A	ROUTE#3 S	ROUTE#3 A	ROUTE#4 S	ROUTE#4 A	ALL S	ALL A
AMD-1B										
5	19	22	30	35	30	31	31	32	110	120
6	0	0	15	19	30	31	34	34	79	84
7	27	29	35	38	28	30	32	34	122	131
8	27	29	34	37	30	31	33	34	124	131
17	25	26	34	36	29	30	33	34	121	126
18	28	29	36	38	19	21	29	31	112	119
19	15	19	31	34	28	29	30	32	104	114
20	18	22	26	28	16	19	28	31	88	100
AMD-3A										
9	20	22	37	38	24	28	30	32	111	120
10	14	18	37	38	29	31	26	30	106	117
11	15	18	0	0	27	29	34	34	76	81
12	12	15	31	34	16	20	0	0	59	69
21	28	29	30	32	30	31	32	33	120	125
22	24	27	35	37	15	18	31	33	105	115
23	26	29	34	38	30	31	31	33	121	131
NP-1C										
13	24	26	31	33	25	26	33	34	113	119
14	0	0	33	35	30	31	31	33	94	99
24	27	29	38	33	26	28	0	0	91	95
25	29	29	30	33	31	31	0	0	90	93
26	29	29	38	38	31	31	33	34	131	132
27	29	29	38	38	31	31	33	34	131	132
TOTAL BY ROUTE										
	436	476	653	697	555	588	564	592	2208	2353
AMD-1B	159	176	241	265	210	222	250	262	860	925
AMD-3A	139	158	204	217	171	188	184	195	698	758
NP-1C	138	142	208	215	174	178	130	135	650	670

Table B6 (Continued)

SAMPLE PROGRAM OUTPUT

PROBABLITIES OF SUCCESS

SUBJECT	ROUTE#1	ROUTE#2	ROUTE#3	ROUTE#4	ALL
AMD-1B					
5	0.86364	0.85714	0.96774	0.96875	0.91667
6	0.00000	0.78947	0.96774	1.00000	0.94048
7	0.93103	0.92105	0.93333	0.94118	0.93130
8	0.93103	0.91892	0.96774	0.97059	0.94656
17	0.96154	0.94444	0.96667	0.97059	0.96032
18	0.96552	0.94737	0.90476	0.93548	0.94118
19	0.78947	0.91176	0.96552	0.93750	0.91228
20	0.81818	0.92857	0.84211	0.90323	0.88000
AMD-3A					
9	0.90909	0.97368	0.85714	0.93750	0.92500
10	0.77778	0.97368	0.93548	0.86667	0.90598
11	0.83333	0.00000	0.93103	1.00000	0.93827
12	0.80000	0.91176	0.80000	0.00000	0.85507
21	0.96552	0.93750	0.96774	0.96970	0.96000
22	0.88889	0.94595	0.83333	0.93939	0.91304
23	0.89655	0.89474	0.96774	0.93939	0.92366
NP-1C					
13	0.92308	0.93939	0.96154	0.97059	0.94958
14	0.00000	0.94286	0.96774	0.93939	0.94949
24	0.93103	1.00000	0.92857	0.00000	0.95789
25	1.00000	0.90909	1.00000	0.00000	0.96774
26	1.00000	1.00000	1.00000	0.97059	0.99242
27	1.00000	1.00000	1.00000	0.97059	0.99242
BY ROUTE	0.91597	0.93687	0.94388	0.95270	0.93838
AMD-1B	0.90341	0.90943	0.94595	0.95420	0.92973
AMD-3A	0.87975	0.94009	0.90957	0.94359	0.92084
NP-1C	0.97183	0.96744	0.97753	0.96296	0.97015

AVERAGE OF SUBJECT PROBABILITIES

AMD-1B	0.89435	0.90234	0.93945	0.95341	0.92360
AMD-3A	0.86731	0.93955	0.89593	0.94211	0.91729
NP-1C	0.97032	0.96522	0.97631	0.96279	0.96320
ALL	0.90451	0.93237	0.93647	0.95173	0.93616

STOP, <>
?

Table B6 (Continued)

SAMPLE PROGRAM OUTPUT

```
C **PROGRAM CERROR 4/24/78
C ** ARI C-7
C ** TO DETERMINE THE NUMBER OF
C ** ATTEMPTS AND SUCCESS FOR EACH
C ** SUBJECT FOR THE INTERVALS OF
C ** OF INTEREST
      DIMENSION LC(150,5),IC(2,5,30),IRTOT(5),PM(5),
     _ IMCT(2,3,5),ISI(30),ISN(21),MAP(4,3),
     _ SPM(21,5),SNP(4,5),APM(4,5)
      DATA LC/750*0/,IC/300*0/,IRTOT/5*0/,PM/5*0.0/,
     _ IMCT/30*0/,ISI/4*0,1,2,3,4,
     _ 9,10,11,12,16,17,0,0,5,6,7,8,13,14,15,18,19,20,21,3*0/,
     _ ISN/5,6,7,8,17,18,19,20,9,10,11,12,21,22,23,
     _ 13,14,24,25,26,27/,MAP/'AM','AM','NP','AL','D-','D-',
     _ '-I','L ','1B','3A','C ','  '/,SPM/105*0.0/,
     _ SNP/20*0.0/,APM/20*0.0/
C **
      ITINT=0
C ** READ INTERVAL SET
C **
      DO 100 I=1,150
      READ(1,1000,END=110) (LC(I,J),J=1,5)
      IF(LC(I,1).EQ.99) GO TO 800
      ITINT=ITINT+1
      IRB=LC(I,1)
      IRTOT(IRB)=IRTOT(IRB)+1
  100 CONTINUE
  110 CONTINUE
      IRTOT(5)=ITINT
C **
C ** SET ALL COUNTS TO THE
C ** MAXIMUM NUMBER OF ATTEMPTS
      DO 210 I=1,4
      DO 200 J=1,21
      IC(1,I,J)=IRTOT(I)
      IC(2,I,J)=IRTOT(I)
  200 CONTINUE
  210 CONTINUE
C **
C ** FOR EACH OF FOUR ROUTES
      DO 340 I=1,4
C ** FOR EACH OF 21 POSSIBLE FLIGHTS
      DO 330 J=1,21
      READ(2,2000) ISBIN,IRT,ITR,IER,IMS
      ISB=ISI(ISBIN)
      IF(ITR.GT.0) GO TO 300
C ** FLIGHT NOT FLOWN
      IC(1,IRT,ISB)=0
      IC(2,IRT,ISB)=0
      GO TO 330
  300 CONTINUE
      IRD=IER+IMS
C ** CHECK TO SEE IF NO MISSES OR ERRORS
      IF(IRD.LT.1) GO TO 330
C ** FOR EACH INTERVAL OF INTEREST
      DO 320 K=1,IRD
```

Table B6 (Continued)

SAMPLE PROGRAM OUTPUT

```
      READ(2,2100) ITP,IMPLOC
      DO 310 M=1,ITINT
      IF(IRT.NE.LC(M,1)) GO TO 310
      IF((IMPLOC.LT.LC(M,4)).OR.
     _ (IMPLOC.GE.LC(M,5))) GO TO 310
C ** FOR MISSES
      IF(ITP.LE.0)IC(1,IRT,ISB)=
     _ IC(1,IRT,ISB)-1
      IF(ITP.LE.0)IC(2,IRT,ISB)=
     _ IC(2,IRT,ISB)-1
C ** FOR ERRORS
      IF(ITP.GT.0)IC(1,IRT,ISB)=
     _ IC(1,IRT,ISB)-1
  310 CONTINUE
  320 CONTINUE
  330 CONTINUE
  340 CONTINUE
C **
C **
C ** FIND ROW AND COLUMN TOTALS
C **
      DO 410 I=1,4
      DO 400 J=1,21
      IC(1,5,J)=IC(1,5,J)+IC(1,I,J)
      IC(2,5,J)=IC(2,5,J)+IC(2,I,J)
      IC(1,I,30)=IC(1,I,30)+IC(1,I,J)
      IC(2,I,30)=IC(2,I,30)+IC(2,I,J)
      IC(1,5,30)=IC(1,5,30)+IC(1,I,J)
      IC(2,5,30)=IC(2,5,30)+IC(2,I,J)
  400 CONTINUE
  410 CONTINUE
C **
C ** PRINT COUNTS
C **
      WRITE(6,9000) (IRTOT(L),L=1,5)
      DO 500 K=1,21
      IF(K.EQ.1) WRITE(6,9501) MAP(1,1),MAP(1,2),MAP(1,3)
      IF(K.EQ.9) WRITE(6,9501) MAP(2,1),MAP(2,2),MAP(2,3)
      IF(K.EQ.16) WRITE(6,9501) MAP(3,1),MAP(3,2),MAP(3,3)
      IS=ISN(K)
      WRITE(6,9100) IS,IC(1,1,K),IC(2,1,K),IC(1,2,K),IC(2,2,K),
     _ IC(1,3,K),IC(2,3,K),IC(1,4,K),IC(2,4,K),IC(1,5,K),IC(2,5,K)
  500 CONTINUE
      WRITE(6,9200)
      WRITE(6,9300) IC(1,1,30),IC(2,1,30),IC(1,2,30),IC(2,2,30),
     _ IC(1,3,30),IC(2,3,30),IC(1,4,30),IC(2,4,30),
     _ IC(1,5,30),IC(2,5,30)
C **
C ** FIND MAP TOTALS AND PRINT
      DO 510 KK=1,3
      JST=1
      JSP=8
      IF(KK.EQ.2) JST=9
      IF(KK.EQ.2) JSP=15
      IF(KK.EQ.3) JST=16
      IF(KK.EQ.3) JSP=21
```

SAMPLE PROGRAM OUTPUT

```
      DO 510 I=1,4
      DO 510 J=JST,JSP
      IMCT(1,KK,I)=IMCT(1,KK,I)+IC(1,I,J)
      IMCT(2,KK,I)=IMCT(2,KK,I)+IC(2,I,J)
      IMCT(1,KK,5)=IMCT(1,KK,5)+IC(1,I,J)
      IMCT(2,KK,5)=IMCT(2,KK,5)+IC(2,I,J)
  510 CONTINUE
      DO 520 KK=1,3
      WRITE(6,9301) MAP(KK,1),MAP(KK,2),MAP(KK,3),
     _ IMCT(1,KK,1),IMCT(2,KK,1),IMCT(1,KK,2),
     _ IMCT(2,KK,2),IMCT(1,KK,3),IMCT(2,KK,3),IMCT(1,KK,4),
     _ IMCT(2,KK,4),IMCT(1,KK,5),IMCT(2,KK,5)
  520 CONTINUE
C **
C ** COMPUTE AND PRINT PROBABLITIES
      WRITE(6,9400)
      DO 630 K=1,21
      IF(K.EQ.1) WRITE(6,9501) MAP(1,1),MAP(1,2),MAP(1,3)
      IF(K.EQ.5) WRITE(6,9501) MAP(2,1),MAP(2,2),MAP(2,3)
      IF(K.EQ.16) WRITE(6,9501) MAP(3,1),MAP(3,2),MAP(3,3)
      IS=ISN(K)
      DO 610 M=1,5
      C1=FLOAT(IC(1,M,K))
      C2=FLOAT(IC(2,M,K))
      IF(IC(2,M,K).LE.0) PM(M)=0.0
      IF(IC(2,M,K).GT.0) PM(M)=C1/C2
      SPM(K,M)=PM(M)
  610 CONTINUE
      WRITE(6,9500) IS,(PM(L),L=1,5)
  630 CONTINUE
      DO 640 M=1,5
      C1=FLOAT(IC(1,M,30))
      C2=FLOAT(IC(2,M,30))
      IF(IC(2,M,30).LE.0) PM(M)=0.0
      IF(IC(2,M,30).GT.0) PM(M)=C1/C2
  640 CONTINUE
      WRITE(6,9600)
      WRITE(6,9700) (PM(L),L=1,5)
      DO 660 KK=1,3
      DO 650 M=1,5
      C1=FLOAT(IMCT(1,KK,M))
      C2=FLOAT(IMCT(2,KK,M))
      IF(IMCT(2,KK,M).LE.0) PM(M)=0.0
      IF(IMCT(2,KK,M).GT.0) PM(M)=C1/C2
  650 CONTINUE
      WRITE(6,9701) MAP(KK,1),MAP(KK,2),MAP(KK,3),
     _ (PM(L),L=1,5)
  660 CONTINUE
C **
C **
C ** COMPUTE AND PRINT AVERAGE OF
C ** SUBJECT PROBABLITIES
      WRITE(6,9800)
      DO 740 KK=1,4
      JST=1
      JSP=8
```

Table B6 (Concluded)

SAMPLE PROGRAM OUTPUT

```
      IF(KK.EQ.2) JST=9
      IF(KK.EQ.2) JSP=15
      IF(KK.EQ.3) JST=16
      IF(KK.EQ.3) JSP=21
      IF(KK.EQ.4) JST=1
      IF(KK.EQ.4) JSP=21
      DO 720 M=1,5
      DO 710 J=JST,JSP
      IF(IC(2,M,J).LE.0) GO TO 710
      SNP(KK,M)=SNP(KK,M)+1.0
      APM(KK,M)=APM(KK,M)+SPM(J,M)
  710 CONTINUE
  720 CONTINUE
      DO 730 M=1,5
      IF(SNP(KK,M).LE.0.0) APM(KK,M)=0.0
      IF(SNP(KK,M).GT.0.0) APM(KK,M)=APM(KK,M)/SNP(KK,M)
  730 CONTINUE
      WRITE(6,9900) MAP(KK,1),MAP(KK,2),MAP(KK,3),
     _ (APM(KK,L),L=1,5)
  740 CONTINUE
C **
C **
C ** OUTPUT RESULT FILE OF SUBJECT P(S)
      DO 750 K=1,21
      WRITE(3,3000) (SPM(K,M),M=1,5)
  750 CONTINUE
  600 CONTINUE
      STOP
 1000 FORMAT(516)
 2000 FORMAT(5I5)
 2100 FORMAT(2I5)
 9000 FORMAT('1','COUNT OF ATTEMPTS (A) AND',
     _     ' SUCCESSES (S) FOR DEFINED PATTERN'/' ',
     _ 'NUMBER OF INTERVALS'/' ',
     _ 'ROUTE 1',I5/' ',
     _ 'ROUTE 2',I5/' ',
     _ 'ROUTE 3',I5/' ',
     _ 'ROUTE 4',I5/' ',
     _ 'ALL    ',I5/' ',
     _ 'SUB',3X,'ROUTE 1',3X,'ROUTE 2',3X,'ROUTE 3',
     _ 3X,'ROUTE 4',7X,'ALL'/' ',
     _ 3X,5('    S    A'))
 9100 FORMAT(' ',I3,10I5)
 9200 FORMAT(' ','TOTAL BY ROUTE')
 9300 FORMAT(' ',3X,10I5)
 9400 FORMAT('1','PROBABLITIES OF SUCCESS'/' ',
     _ 'SUBJECT',3X,'ROUTE 1',3X,'ROUTE 2',3X,'ROUTE 3',
     _ 3X,'ROUTE 4',7X,'ALL')
 9500 FORMAT(' ',I7,5(2X,F8.5))
 9600 FORMAT(' ','BY ROUTE')
 9700 FORMAT(' ',7X,5(2X,F8.5))
 9301 FORMAT(' ',3A2/' ',3X,10I5)
 9701 FORMAT(' ',3A2/' ',7X,5(2X,F8.5))
 9800 FORMAT(' ','AVERAGE OF SUBJECT PROBABILITIES')
 9900 FORMAT(' ',3A2/' ',7X,5(2X,F8.5))
 3000 FORMAT(5F7.3)
 9901 FORMAT(' ',3A2/' ')
      END
```

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